RESULTS OF THE STUDY OF EFFECTS OF THE RABBIT LAKE MINEWATER SPILL, NOVEMBER 6-7, 1989

by

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EXECUTIVE SUMMARY

A study of water, sediments and fish in Collins Creek and Collins Bay was conducted in order to determine the effects of the spill of minewater from the Cameco uranium operation at Rabbit Lake.

Water, sediments and fish were collected from sites upstream and downstream of the spill site and analysed for radionuclides and metals. Data were examined for increases downstream compared with upstream, for increases compared with background or monitoring data and for differences with data from other northern Saskatchewan lakes.

Results indicated that the only water quality parameter that increased downstream of the spill was uranium. This increase was small and short-lived. Longer-term trends in water quality may be related to fluctuations in runoff from year to year as well as to the effects of exploration, construction and mining adjacent to Collins Bay.

There were no observed increases in sediment radionuclides or metals as a result of the spill; however logistical problems with sediment sampling prevented the taking of a sediment surface layer thin enough to be truly representative of the conditions immediately post-spill. There have been increases in uranium, lead-210 and some metals in the top 5 cm of sediments compared to lower sediment layers.

Fish radionuclide levels in the samples taken after the spill were not distinguishable from background. The dose to people from eating fish from Collins Bay once a week for a year would be 0.7% of the annual dose limit for the general public; this is not a significant dose. There is no cause for concern with respect to radionuclides in Collins Bay fish.

Arsenic and copper levels in the post-spill fish samples were greater than background or monitoring samples and were also greater than most levels recorded for fish in other northern Saskatchewan lakes. The causes of the greater arsenic and copper levels in Collins Bay fish are unknown; it is unlikely that the spill caused these increases because water quality and sediment quality data did not show significant increases in these parameters after the spill. Arsenic and copper levels in Collins Bay fish are not of concern with respect to consumption by humans.

The scarcity of monitoring data for fish and sediments from Wollaston Lake (especially for Collins Bay) made a thorough interpretation of data from this study difficult. However, I am confident that this study provides reliable information that can be used as a basis for comparison with future studies.

There are several recommended follow-up studies. Continued close monitoring of water quality in Collins Bay, accompanied by supporting data on runoff and relevant information about background geology, exploration, construction and mining activities adjacent to the bay is necessary. Studies of sediment radionuclide and metal levels should continue, with emphasis on collection of core samples in several locations and including replication at each sample site. Fish should be collected in early spring to confirm that radionuclide levels remain at background and there are no delayed effects of the spill via the food chain. The causes of the increasing trend in arsenic and copper levels in fish should be investigated.

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1 DESCRIPTION OF SPILL AND RATIONALE OF STUDY

A spill of minewater occurred at the Cameco uranium mining operation at Rabbit Lake on the night of November 6, 1989. The spill resulted in the release of 1,925 m^3 of minewater to the environment. The minewater entered Collins Creek approximately 2 km upstream of Collins Bay. The minewater contained 3-4 Bq/L total radium-226, 150-760 ug/L total arsenic, 0.22-0.3 mg/L total nickel and 229-320 mg/L total suspended solids (Mines Pollution Control Branch 1989).

The purpose of this study was to sample water, sediments and fish from Collins Creek and Collins Bay, measure radionuclide and metal levels and interpret the results with respect to possible effects of the spill.

The scope of this study was limited to the collection of two fish species at one general location and the collection of sediments at five sites. A fully comprehensive study of fish and sediments would have involved far more samples than were taken during this study; however, we are confident that the design of this study is such that the resulting information is reliable and can be used to draw some conclusions about the effects of the spill. In addition, we have included a review of past monitoring data from Wollaston Lake as well as data from other northern Saskatchewan lakes to aid our interpretation of results.

2 METHODS

Sampling sites were selected to represent conditions upstream of the spill in Collins Creek, conditions immediately downstream of the spill in Collins Creek and conditions in Collins Bay at the mouth of Collins Creek and farther out into the bay (Figure 1).

Water samples were taken from below the ice with a Kemmerer water sampler and placed in rinsed plastic containers. Samples for radionuclides and metals were preserved immediately with nitric acid. Samples from Collins Bay were a composite of surface, middle and bottom water. Conductivity/oxygen/temperature profiles were taken at both Collins Bay sites. Alkalinity and pH were also measured on site. Temperature, oxygen, conductivity, pH and alkalinity were also measured at the creek sites.

Three replicate sediment samples were taken at each sediment site. The creek samples at sites 1 and 2 were taken with a brass corer with an inner acrylic tube. Creek sediments were primarily sand/gravel; the corer could not penetrate beyond 5 cm and retaining the sediment core was very difficult. Therefore, the creek sediment samples are all surface samples representing 0-5 cm. The lake sediment samples and creek sample 5 were taken with a KB corer. In these locations, the sediments were more easily penetrated; therefore, each sample was divided into an upper 0-5 cm section and a lower 5-10 cm section. Sediment samples were placed in plastic bags and kept frozen until analysis.

Fish were sampled using a gill net. Initially, the objective was to collect lake whitefish and northern pike. After 5 net sets, no northern pike had been captured. Therefore, longnose suckers were selected as the second species. The lake whitefish were not large

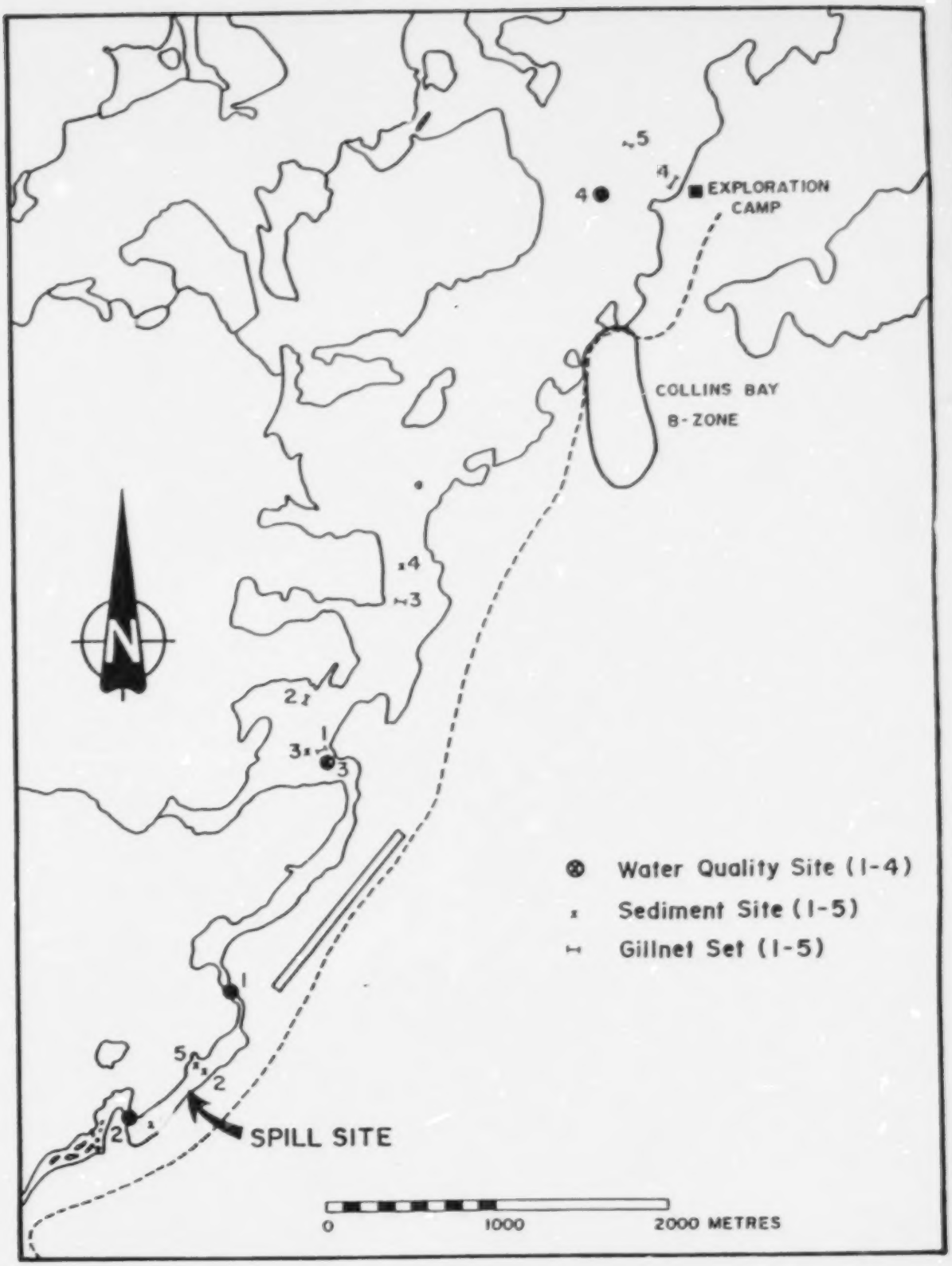

Figure 1. Sampling Locations.

enough for one fish to be used per sample. Therefore, 2-3 fish were combined for one sample to make up five samples in total. The longnose suckers were large enough that individual fish were used for each sample, again five samples were taken in total. The fish were gutted and then frozen whole for analysis. The fish were separated into flesh and bones in the laboratory by placing the samples in boiling bags, cooking them and then removing the flesh from the bones.

All analyses were conducted by the SRC Analytical Laboratory. Major ions and nutrients were determined using Standard Methods (1985). Metals were determined using Inductively Coupled Plasma Atomic Emission Spectrometry. Arsenic was determined by Atomic Absorption Spectrometry. Radium-226 was determined by barium-radium coprecipitation and alpha spectroscopy. Lead-210 was determined by BiOCl precipitation and counting of the bismuth-210 activity. Polonium-210 was determined by deposition on silver and alpha spectroscopy. Thorium-230 was determined by coprecipitation with ceric hydroxide and alpha spectroscopy. Uranium was determined by delayed neutron counting for fish and sediment samples and by ICP-AES for water samples.

Sediment results were statistically analysed for differences among sites and depths using the Statistical Analysis System (SAS) General Linear Models Procedure with Tukey's Studentized Range Test.

Fish bioaccumulation factors were calculated according to the formula: $BF = \frac{\text{Bq/g (or ug) wet weight in fish}}{\text{Bq/ml (or ug) in water}}$

Doses to people from consuming fish were calculated assuming consumption of one 500 g serving of Collins Bay lake whitefish per week for one year using the formula: $D = \sum (U_i C_i) d_{it}$

where D = total weighted committed dose equivalent from all radionuclides i over t target tissues

d = weighted committed dose equivalents per unit intake for each tissue t and nuclide i

U = number of unit intakes

C = concentration (bq/g wet weight) per unit intake (Swanson 1985).

3 RESULTS AND DISCUSSION

3.1 Water Quality

The analysis of samples from Collins Creek showed that the only parameter that increased in response to the spill was uranium. The increase was noted at the sampling site at the Narrows during November 7 to November 8 (Table 2). All other parameters at the Narrows were similar to levels recorded at the site upstream of the spill (Tables 1 and 2).

The increase in uranium noted at the Narrows was short-lived and small in magnitude. The highest level recorded was 0.49 ug/L; the drinking water quality guideline is 100 ug/L.

Samples taken at the mouth of Collins Creek show small amounts of uranium (0.06-0.07 ug/L). These are within the range noted at the site upstream of the spill (Table 3). Comparison of the post-spill samples with monitoring data for September, 1988 (the closest data to November in the monitoring data) was hampered by the higher detection limit (0.5 ug/L) for the uranium analysis in the monitoring data. Monitoring data from September and January, 1988 at the mouth of Collins Creek show uranium as <0.5 ug/L; the analyses after the spill had a detection limit of 0.01 ug/L. Therefore, it is impossible to tell whether there was a slight increase in uranium at the mouth of Collins Creek compared to monitoring data for similar times of the year.

Uranium in samples taken downstream of the B-zone varied from 0.03 to 0.34 ug/L (Table 4). The higher values occurred on November 11, 13 and 17. These values (0.14, 0.11, 0.34) are higher than in samples upstream of the spill but are lower than average uranium levels from

Table 1. Water Quality Upstream of the Spill Site, November, 1989
Collins Creek, 80 m upstream of spill.*

Sample Date	Nov 8/89	Nov 8/89	Nov 8/89	Nov 14/89	Nov 17/89	Nov 18/89
Collector	Cameco	Cameco	MPCB	Cameco	Cameco	SRC Site #2
Depth						
Lab	SRC	NS**	SRC	NS	NS	SRC
pH (pH units)						
Cond (umhos/cm)						
TSS (mg/L)	3					
U (ug/L)	L0.01	L0.01	.02	.05	.06	0.01
Ra 226 (Bq/L)		L0.005	L0.005	L0.005	.02	<0.005
Ra 226 (T,sh)(1)	L0.005		L0.005			
NH3, N (mg/L)						
P (mg/L)						
HCO3 (mg/L)	9					
SO4 (mg/L)	.8					
Ca (mg/L)	1.6		2.4			1.5
Mg (mg/L)	.6		1			0.6
K (mg/L)	.4		.5			0.8
Na (mg/L)	2.6		1.7			1.2
Fe (mg/L)	.21		.21			0.18
Mn (mg/L)			0.013			0.009
Cl (mg/L)	.1					
As (ug/L)	.5	.5	L0.5			<0.5
Ba (mg/L)			L0.001			0.002
B (mg/L)						
Cd (mg/L)			L0.001			<0.001
Cr (mg/L)			.002			<0.001
Co (mg/L)			L0.001			<0.001
Al (mg/L)			L0.005			0.031
Pb (mg/L)	L0.005		L0.005			<0.005
Hg (ug/L)						
Mo (mg/L)			L0.005			<0.005
Ni (mg/L)	.003	.003	L0.001			0.002
Se (mg/L)						
Cu (mg/L)	.002		L0.001			<0.001
V (mg/L)	L0.01		L0.01			<0.01
W (mg/L)			L0.005			<0.005
Zn (mg/L)	L0.005		.009			<0.001
Ag (mg/L)			L0.001			0.001
Pb 210 (Bq/L)						0.03
Po 210 (Bq/L)						<0.005
Th 230 (Bq/L)						0.06

(1) (T,sh) - short ingrowth (rush) Ra-226 analyses

* All data prior to November 18/89 provided by Saskatchewan Environment and Public Safety.

** Not specified.

Table 2. Water Quality in Collins Creek at the Narrows, Downstream of the Spill Site, November, 1989.

Sample Date	Nov 7	Nov 8	Nov 8	Nov 8	Nov 9	Nov 9	Nov 10	Nov 10	Nov 14	Nov 15	Nov 16	Nov 17
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	MPCB	Cameco	MPCB	Cameco	Cameco	Cameco	Cameco
Depth												
Lab	SRC	SRC	SRC	Key L.	Key L.	SRC	SRC	SRC	NS*	NS	NS	NS
pH (pH units)												
Cond (umhos/cm)												
TSS (mg/L)				2	1							
U (ug/L)	.49	.16	.1	L2	L2	.03	.02	.1	.01	.01	L0.01	L0.01
Ra 226 (Bq/L)				L0.01	L0.01	L0.005		L0.005	L0.005	L0.005	L0.005	L0.005
Ra 226 (T,sh) (1)	.01	L0.005	L0.005				.01					
NH3, N (mg/L)												
P (mg/L)												
HCO3 (mg/L)				6.8	6.7							
SO4 (mg/L)				L0.1	L0.1							
Ca (mg/L)					1.61							
Mg (mg/L)				.56	.57							
K (mg/L)				.41	.41							
Na (mg/L)				1.18	1.14							
Fe (mg/L)	.18	.17	.18	.29	.19							
Mn (mg/L)												
Cl (mg/L)				.8	.8							
As (ug/L)	1.1	L0.5	L0.5	L2	L2		L0.05					
Ba (mg/L)												
B (mg/L)												
Cd (mg/L)												
Cr (mg/L)												
Co (mg/L)												
Al (mg/L)												
Pb (mg/L)	L0.005	L0.005	L0.005	L0.01	L0.01							
Hg (ug/L)												
Mo (mg/L)												
Ni (mg/L)	.002	.005	L0.001	L0.005	L0.005		L0.001					
Se (mg/L)												
Cu (mg/L)	.001	L0.001	L0.001	.005	L0.005							
V (mg/L)	L0.01	L0.01	L0.01	L0.005	L0.005							
W (mg/L)												
Zn (mg/L)	L0.005	L0.005	L0.005	.005	.006							
Ag (mg/L)												

(1) (T,sh) - short ingrowth (rush) Ra-226 analyses

* All data prior to November 18/89 provided by Saskatchewan Environment and Public Safety.

** Not specified.

Table 2. (Continued) Collins Creek at Narrows (right side)

Sample Date	Nov 7	Nov 7	Nov 8	Nov 8	Nov 8	Nov 9	Nov 9	Nov 10	Nov 11
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	MPCB	Cameco	MPCB
Depth									
Lab	Rabbit	NS	NS	NS	Key L.	Key L.	SRC	NS	SRC
pH (pH units)							6.83		6.77
Cond (umhos/cm)							20		20
TSS (mg/L)							L1		L1
U (ug/L)		.49	.16	.1	L2	L2		0.2	
Ra 226 (Bq/L)	.02	.005	L0.005	L0.005	L0.01	L0.01		L0.005	
Ra 226 (T,sh) (1)									
NH3, N (mg/L)							L0.5		L0.05
P (mg/L)							9		9
HCO3 (mg/L)							.8		.8
SO4 (mg/L)							1.3		1.3
Ca (mg/L)							.4		.3
Mg (mg/L)							L0.1		.4
K (mg/L)							1		1.2
Na (mg/L)							.22		.21
Fe (mg/L)							.013		.014
Mn (mg/L)							.3		.3
Cl (mg/L)								L0.5	L0.5
As (ug/L)	L50	1.1	L0.5	L0.5	L2	L2	.003		.002
Ba (mg/L)							L0.05		L0.05
B (mg/L)							L0.001		L0.001
Cd (mg/L)							L0.001		L0.001
Cr (mg/L)							L0.001		L0.001
Co (mg/L)							.015		.009
Al (mg/L)							L0.005		L0.005
Pb (mg/L)									
Hg (ug/L)							L0.005		L0.005
Mo (mg/L)									L0.001
Ni (mg/L)	L0.05	.002	.005	L0.001	L0.005	L0.005	.005	L0.001	L0.001
Se (mg/L)							L0.001		L0.001
Cu (mg/L)							L0.01		L0.01
V (mg/L)							L0.005		L0.005
W (mg/L)							.003		L0.001
Zn (mg/L)							L0.001		L0.001
Ag (mg/L)									

(1) (T,sh) - short ingrowth (rush) Ra-226 analyses

Table 2. (Continued) Collins Creek at Narrows (600 m downstream)

Sample Date	Nov 7	Nov 8	Nov 8	Nov 9	Nov 9	Nov 9	Nov 10	Nov 10
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	MPCB	Cameco	Cameco
Depth								
Lab	R.Lake	SRC	K.Lake	K.Lake	NS	SRC	NS	SRC
pH (pH units)								
Cond (umhos/cm)								
TSS (mg/L)								
U (ug/L)		.03	L2	L2	.03	.03	.06	.06
Ra 226 (Bq/L)	L0.01*	L0.005	L0.01	L0.01	.01	L0.005	.005	
Ra 226 (T,sh) (1)						L0.005		.01
NH3, N (mg/L)								
P (mg/L)						L0.05		
HCO3 (mg/L)			7.1	7.5				
SO4 (mg/L)			L0.1	L0.1				
Ca (mg/L)			1.62	1.62		2.7		
Mg (mg/L)			.56	.55		1.3		
K (mg/L)			.44	.42		.9		
Na (mg/L)			1.14	1.15		1.6		
Fe (mg/L)		.18	.21	.19		.23		
Mn (mg/L)						.014		
Cl (mg/L)			.9					
As (ug/L)	L50*	.6	L2	L2	L0.5	L0.5	L0.5	L0.5
Ba (mg/L)						L0.001		
B (mg/L)						L0.05		
Cd (mg/L)						L0.001		
Cr (mg/L)						L0.001		
Co (mg/L)						L0.001		
Al (mg/L)						.019		
Pb (mg/L)		L0.005	L0.01	L0.01		L0.005		
Hg (ug/L)								
Mo (mg/L)						L0.005		
Ni (mg/L)	L0.05*	.001	L0.005	L0.005	L0.001	.001	L0.001	L0.001
Se (mg/L)								
Cu (mg/L)		L0.001		L0.005		L0.001		
V (mg/L)		L0.01	L0.005	L0.005		L0.01		
W (mg/L)						L0.005		
Zn (mg/L)		L0.001	.01	.015		L0.001		
Ag (mg/L)						L0.001		

(1) (T,sh) - short ingrowth (rush) Ra-226 analyses
* means dissolved results

Table 2. (Continued) Collins Creek at Narrows

Sample Date	Nov 7	Nov 8	Nov 8	Nov 9	Nov 10	Nov 18
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	SRC Site 1
Depth						
Lab	R.Lake	SRC	K.Lake	K.Lake	NS	SRC
pH (pH units)						
Cond (umhos/cm)						
TSS (mg/L)			1.8	.8		
U (ug/L)		LO.01	L2	3	.02	0.02
Ra 226 (Bq/L)	LO.01		LO.01	LO.01	.005	<0.005
Ra 226 (T,sh) (1)		LO.001				
NH3, N (mg/L)						
P (mg/L)						
HCO3 (mg/L)			6.8	7.2		
SO4 (mg/L)			LO.1	LO.1		
Ca (mg/L)			1.62	1.62		1.5
Mg (mg/L)			.55	.56		0.6
K (mg/L)			.42	.45		0.4
Na (mg/L)			1.17	1.13		1.1
Fe (mg/L)		.17	.22	.19		0.16
Mn (mg/L)						0.009
Cl (mg/L)			.9	.7		
As (ug/L)	1.1*	1.1	L20	L20	LO.5	<0.5
Ba (mg/L)						0.002
B (mg/L)						0.1
Cd (mg/L)						<0.001
Cr (mg/L)						<0.001
Co (mg/L)						<0.001
Al (mg/L)						0.013
Pb (mg/L)		LO.005	LO.01	LO.01		<0.005
Hg (ug/L)						
Mo (mg/L)						<0.005
Ni (mg/L)	LO.05*	.002	LO.001	LO.005	LO.001	0.003
Se (mg/L)						
Cu (mg/L)		LO.001	LO.005	LO.005		<0.001
V (mg/L)		LO.01	LO.005	LO.005		<0.01
W (mg/L)						0.006
Zn (mg/L)		LO.005	.005	.008		<0.001
Ag (mg/L)						0.001
Pb 210 (Bq/L)						0.07
Po 210 (Bq/L)						<0.005
Th 230 (Bq/L)						<0.01

Table 3. Water Quality in Collins Bay at the Mouth of Collins Creek: 1985-1989; Collins Bay at Mouth of Creek.*

Sample Date	1985 (1)	1987 (2)	1988 (3)	Nov 9/89	Nov 9/89	Nov 19/89
Collector	Cameco	Cameco	Cameco	MPCB	Env Can	SRC Site 3
Depth						
Lab	NS**	NS	NS	SRC	NS	SRC
pH (pH units)	5.6	6.05	6.62			
Cond (umhos/cm)	23.25	20.5	22.25			
TSS (mg/L)	1.1	.6	1.8			
U (ug/L)	2.3	.63	.5	.06	.06	0.07
Ra 226 (Bq/L)	LO.005	.005	.005	LO.005	LO.005	<0.005
Ra 226 (T,sh) (1)				LO.005		
NHD, N (mg/L)		.05	.06			
P (mg/L)				LO.05		
HCO3 (mg/L)	13	14	11			
SO4 (mg/L)	2.5	1.83	.68			
Ca (mg/L)	2.4	1.55	1.63	1.8		1.6
Mg (mg/L)	.73	.73	.62	.7		0.6
K (mg/L)	.6	.5	.18	1.8		0.6
Na (mg/L)	1.4	1.63	1.47	1.3		1.2
Fe (mg/L)		.221	.216	.21		0.16
Mn (mg/L)		.028	.015	.01		0.008
Cl (mg/L)						
As (ug/L)	LO.01	.77	.5	LO.5	LO.5	<0.5
Ba (mg/L)		.015	.009	LO.001		0.002
B (mg/L)		.041	.032	LO.05		<0.05
Cd (mg/L)	LO.003	.003	.002	LO.001		<0.001
Cr (mg/L)	.021	.006	.004	.003		<0.001
Co (mg/L)		.006	.004	LO.001		<0.001
Al (mg/L)		.02	.016	.011		0.012
Pb (mg/L)		.02	.01	LO.005		<0.005
Hg (ug/L)	.05	.73	.05			
Mo (mg/L)		.08	.008	LO.005		<0.005
Ni (mg/L)	LO.010	.018	.006	.004	.004	0.002
Se (mg/L)	.002	.001	.001			
Cu (mg/L)	.004	.01	.002	LO.001		0.003
V (mg/L)	LO.010	.005	.008	LO.01		<0.01
W (mg/L)				LO.005		<0.005
Zn (mg/L)	.215	.008	.005	.017		<0.001
Ag (mg/L)		.004	.002	LO.001		0.002

* All data prior to November 18/89 provided by Saskatchewan Environment and Public Safety.
** Not specified.

Table 3. (Continued): Collins Bay at Mouth of Creek.

Sample Date	1985 (1)	1987 (2)	1988 (3)	Nov 9/89	Nov 9/89	Nov 19/89
Pb 210 (Bq/L)						<0.02
Po 210 (Bq/L)						<0.005
Th 230 (Bq/L)						0.03

(1) 1985 means from A, D, Eagle Elk May, 1986 Number of samples range from 1 - 4.

(2) 1987 means from Cameco 1988 Annual Report Number of samples range from 1 - 4.

(3) 1988 means from Cameco 1988 Annual Report Number of samples range from 1 - 4.

Table 4. Water Quality in Collins Bay Downstream of the B-Zone Pit: 1985-1989; Collins Bay Mid, Downstream of B-Zone.*

Sample Date	1985 (1)	1986(2)	1987 (3)	1988 (4)	Nov 11	Nov 11	Nov 11	Nov 11	Nov 13	Nov 14	Nov 14/89
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	MPCB	MPCB	MPCB	Cameco
Depth					Bottom	Middle	Top	Comp	Comp	Comp	Top
Lab	NS**	NS	NS	NS	SRC	SRC	SRC	SRC	SRC	SRC	NS
pH (pH units)	5.87	6.14	6.13	6.61				6.81			
Cond (umhos/cm)	29.75	26.6	24.5	29.33				23			
TSS (mg/L)	.5	.76	.45	1.2				L1			
U (ug/L)	1.92	1.2	.5	.5	.03	.05	.03	.05	.14	.11	.07
Ra 226 (Bq/L)	L0.005	.005	.015	.007	L0.005	.005	L0.005				.005
Ra 226 (T,sh) (1)					L0.005	.005	.01	.005	.01	.005	
NH3, N (mg/L)		.08	.05	.05							
P (mg/L)								L0.05	L0.05		
HCO3 (mg/L)	13.5	14	14.75	13.33				9	9		
SO4 (mg/L)	2.75	2.43	2.45	2.87				1.4	.8		
Ca (mg/L)	2.78	2.25	1.93	2.13				1.6	1.4		
Mg (mg/L)	1	.95	.98	1				.5	.4		
K (mg/L)	.35	.4	.7	.17				.4	.4		
Na (mg/L)	1.4	1.55	1.63	1.3				1.3	1.3		
Fe (mg/L)		.131	.117	.095				.15	.2		
Mn (mg/L)		.024	.013	.009				.012	.013		
Cl (mg/L)	.43	.4	.28	.33				.3	.3		
As (ug/L)	L1.0	.76	.68	.5	L0.5	L0.5	L0.5	L0.5	L0.5		
Ba (mg/L)		.025	.019	.009				.003	.002		
B (mg/L)		.056	.045	.03				L0.05	L0.05		
Cd (mg/L)	.009	.024	.004	.002				L0.001	L0.001		
Cr (mg/L)	.029	.025	.005	.003				L0.001	L0.001		
Co (mg/L)		.007	.007	.004				L0.001	L0.001		
Al (mg/L)		.02	.02	.022				.007	.007		
Pb (mg/L)	.06	.026	.02	.01				L0.005	L0.005		
Hg (ug/L)	.13	.04	.04	.05							
Mo (mg/L)		.09	.01	.003				L0.005	L0.005		
Ni (mg/L)	L0.10	.01	.02	.005	L0.001	L0.001	L0.001	.002	.003		
Se (mg/L)	L0.001	.001	.001	.001							
Cu (mg/L)	.011	.009	.009	.003				L0.001	L0.001		

Table 4. (Continued) Collins Bay Mid, Downstream of B-Zone.

Sample Date	1985 (1)	1986(2)	1987 (3)	1988 (4)	Nov 11	Nov 11	Nov 11	Nov 11	Nov 13	Nov 14	Nov 14/89
V (mg/L)	LO.010	.005	.005	.008				LO.01	LO.01		
W (mg/L)								LO.005	LO.005		
Zn (mg/L)	.033	.031	.014	.007				.002	.009		
Ag (mg/L)		.004	.003	.002				LO.001	LO.001		

(1) 1985 means from A, D, Eagle E18 May, 1986
Number of samples range from 1 - 4.

(2) 1987 means from Cameco 1988 Annual Report
Number of samples range from 1 - 4.

(3) 1988 means from Cameco 1988 Annual Report
Number of samples range from 1 - 4.

(4) 1988 means from Cameco 1988 Annual Report
Number of samples range from 1 - 4.

(5) (T,Sh) short ingrowth (rush) Ra-226 analyses.

* All data prior to November 18/89 provided by Saskatchewan Environment and Public Safety.
** Not specified.

Table 4. (Continued) Collins Bay Mid, Downstream of B-Zone.

Sample Date	Nov 15	Nov 15	Nov 15	Nov 16	Nov 16	Nov 16	Nov 17	Nov 17/89
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco
Depth	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle
Lab	NS	NS	NS	NS	NS	NS	NS	NS
pH (pH units)								
Cond (umhos/cm)								
TSS (mg/L)								
U (ug/L)	.04	.01	.04	.06	.01	.01	.34	.01
Ra 226 (Bq/L)	.005	.005	LO.005	.01	.01	LO.005	.01	LO.005
Ra 226 (T,sh)(1)								
NH3, N (mg/L)								
P (mg/L)								
HCO3 (mg/L)								
SO4 (mg/L)								
Ca (mg/L)								
Mg (mg/L)								
K (mg/L)								
Na (mg/L)								
Fe (mg/L)								
Mn (mg/L)								
Cl (mg/L)								
As (ug/L)								
Ba (mg/L)								
B (mg/L)								
Cd (mg/L)								
Cr (mg/L)								
Co (mg/L)								
Al (mg/L)								
Pb (mg/L)								
Hg (ug/L)								
Mo (mg/L)								
Ni (mg/L)								
Se (mg/L)								
Cu (mg/L)								
V (mg/L)								
W (mg/L)								
Zn (mg/L)								
Ag (mg/L)								

Table 4. (Continued) Collins Bay Mid, Downstream.

Sample Date	Nov 19	Nov 19	Nov 19	Nov 20	Nov 20	Nov 20	Nov 18	Nov 18	Nov/18	Nov 19/89
Collector	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	Cameco	SRC
Depth	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Composite
Lab	NS	NS	NS	NS	NS	NS	NS	NS	NS	SRC
pH (pH units)										
Cond (umhos/cm)										
TSS (mg/L)										
U (ug/L)	.45	.01	LD.01	.11	.02	.02	.7	.02	.03	0.04
Ra 226 (Bq/L)	.01	LD.005	LD.005	LD.005	LD.005	LD.005	.02	.005	LD.005	<0.005
Ra 226 (T,sh)(1)										
NH3, N (mg/L)										
P (mg/L)										
HCO3 (mg/L)										
SO4 (mg/L)										
Ca (mg/L)										2.4
Mg (mg/L)										1.0
K (mg/L)										0.3
Na (mg/L)										1.3
Fe (mg/L)										0.094
Mn (mg/L)										0.009
Cl (mg/L)										
As (ug/L)										<0.05
Ba (mg/L)										0.003
B (mg/L)										<0.05
Cd (mg/L)										<0.001
Cr (mg/L)										0.002
Co (mg/L)										<0.001
Al (mg/L)										0.01
Pb (mg/L)										<0.005
Hg (ug/L)										
Mo (mg/L)										<0.005
Ni (mg/L)										0.003
Se (mg/L)										
Cu (mg/L)										0.002
V (mg/L)										<0.01
W (mg/L)										<0.005
Zn (mg/L)										<0.001
Ag (mg/L)										0.03
Pb 210 (Bq/L)										<0.005
Po 210 (Bq/L)										<0.01
Th 230 (Bq/L)										

monitoring in 1985-88 (Tables 1 and 4). Again, there is a difficulty with comparing post-spill data with monitoring data because of differences in detection limits. Post-spill samples were all above the new detection limit of 0.01 ug but below the old limit of 0.5 ug. The winter monitoring data for the mid-Collins Bay site were all below the old detection limit; therefore, if there were slight increases in uranium, they cannot be detected.

Arsenic was not detectable in the post-spill samples; winter monitoring data show arsenic below detection limits as well. Both uranium and arsenic in the post-spill samples were lower than overall mean levels from monitoring for 1985-88.

Nickel levels in Collins Creek immediately downstream of the spill and in Collins Bay at the mouth of Collins Creek were either below detection limits or just slightly above (Tables 2 and 3). These data are similar to previous monitoring data from the mouth of Collins Creek.

Other water quality parameters did not differ from previous monitoring data; that is, radionuclides and metals were usually below detection limits or just slightly above.

Baseline water quality parameters were reviewed in order that the more recent monitoring data could be put into the context of pre-development conditions. Baseline radionuclide levels were all below detection limit except for uranium, which was measured at 0.2-0.3 ug/L in 1979 (Gulf 1980). Arsenic and trace metals were all near or below detection limits. Major ions baseline data are summarized in Table 5.

Comparisons with baseline data show that uranium has shown an increase and then a decrease back to near-background levels over time.

Table 5. Baseline data for major ions (from Gulf 1980).

Comparative Data On Ionic Composition Collins Bay, Wollaston Lake 1979

	Parameter	1979 Collins Bay Mean	Wollaston Lake (Rawson 1959)	Collins Bay (Sawchyn 1973)	Wollaston Lake (Armstrong and Schindler 1971)
Ca	(Calcium)	2.6	3.6 - 4.1	0.9 - 3.7	2.6
Mg	(magnesium)	0.85	7.5	0.6 - 1.3	1.8
Na	(sodium)	0.83	0.42	1.1 - 1.5	0.4
K	(potassium)	2.7	-	0.4 - 0.8	2.5
CO_3	(carbonate)	5.3	11.6 - 14.9	-	11.8
SO_4	(sulphate)	3.04	0.6 - 0.7	-	5.8
Cl	(chloride)	0.51	0 - 2.9	-	0.4

units = mg/l

Arsenic has followed a similar trend. Major ions have fluctuated within the ranges recorded for baseline.

The EIS for the Collins Bay A-Zone, D-Zone and Eagle Point (Cameco 1986) discusses the increasing trend in uranium in Collins Bay and in other more remote stations such as the Umpherville River and suggests that variation in laboratory techniques for uranium may be a contributing factor. However, since arsenic and two major ions also show some increases, an alternative explanation may be the effects of precipitation and runoff from the drainage basin.

Total precipitation data for Collins Bay indicate that the years 1983-1986 had above average precipitation following two years of low precipitation (Table 6). The baseline year of 1979 appeared to have had below-average precipitation, although data from September are missing. Runoff data show a very low period in 1981-82, followed by a gradual climb back up during 1983-86 (Figures 2 and 3). Precipitation was below normal in 1987 and increased to above normal again in 1988.

When the precipitation and runoff data are compared to trends in uranium, TSS and radium-226 (Figure 4), it is apparent that there is some correspondence. Thus, higher inputs of uranium and radium-226 from the watershed during higher runoff years may explain the increasing trend noted in the 1986 EIS. The higher arsenic levels could also be explained this way. Thus, the lower levels of uranium and arsenic in the water quality monitoring report for 1988 may reflect the very low runoff for 1987-88.

It is notable that many of the water quality parameters measured in November, 1989 are much lower than yearly mean levels. Again, this can

Table 6. Total Precipitation For Collins Bay 1975 - 1988.

Year	Precipitation (mm)
1975	495.1
1976	710.8
1977	675.6
1978	567.0
1979	N/A
1980	534.7
1981	382.6
1982	476.0
1983	602.1
1984	N/A
1985	614.0
1986	635.7
1987	431.1
1988	668.5

Longterm Average (8 yrs of record) 522.6
Longterm Average for Wollaston Lake 425.7 (8 yrs of record).

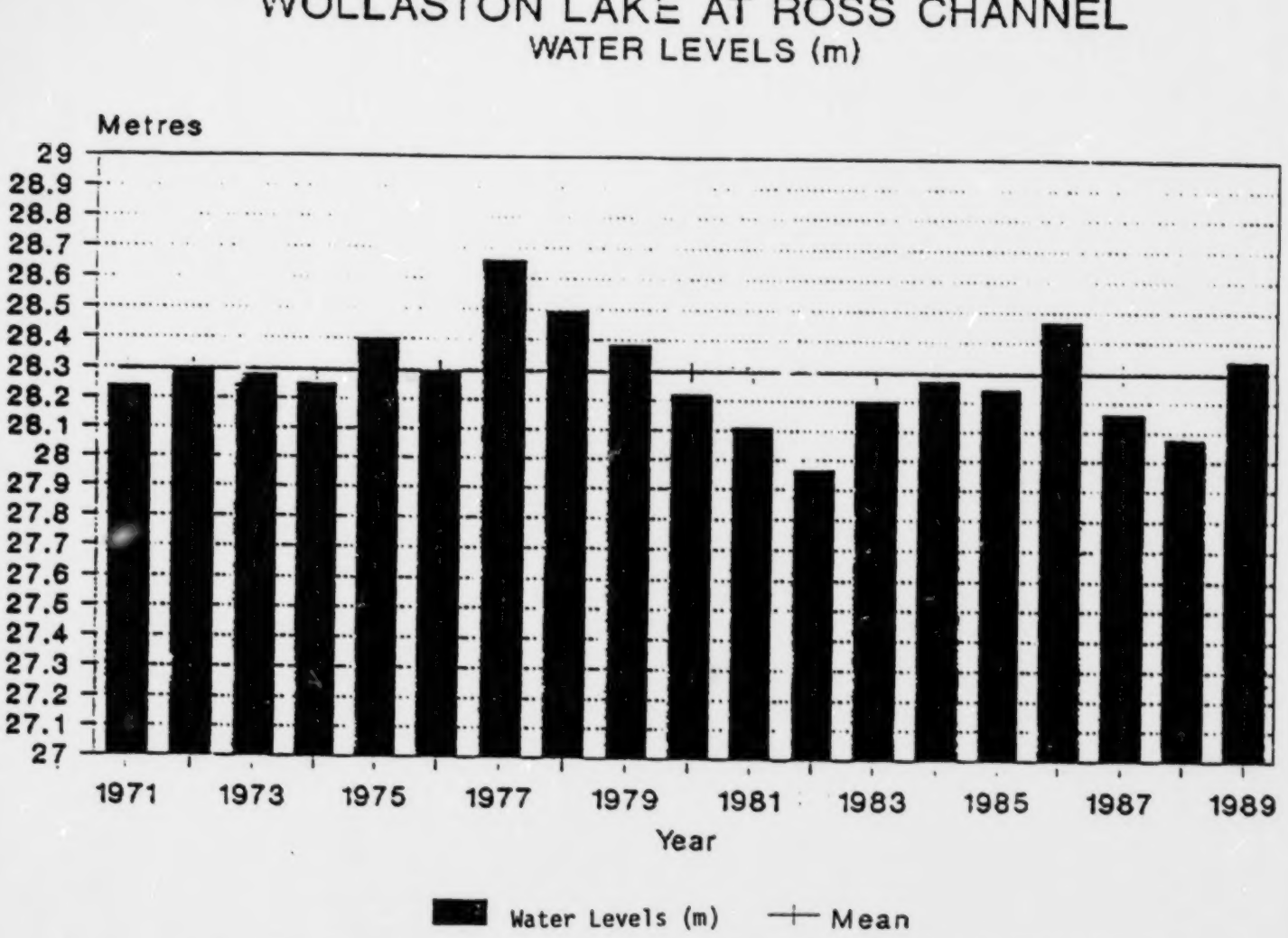

Figure 2. Water levels in Wollaston Lake 1971-89 (from Environment Canada Water Survey).

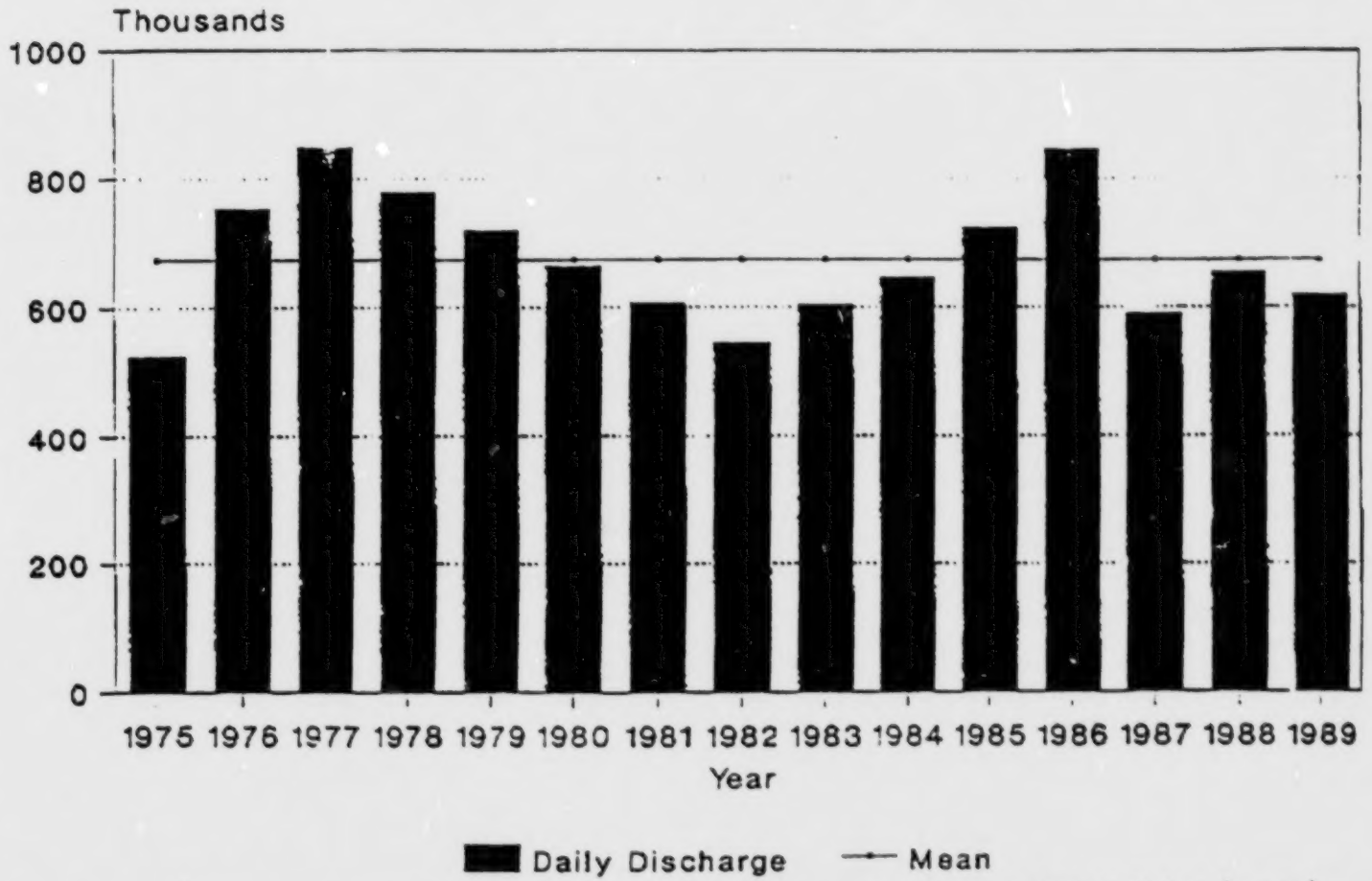

Figure 3. Discharges in the Waterfound River 1975-89 (from Environment Canada Water Survey).

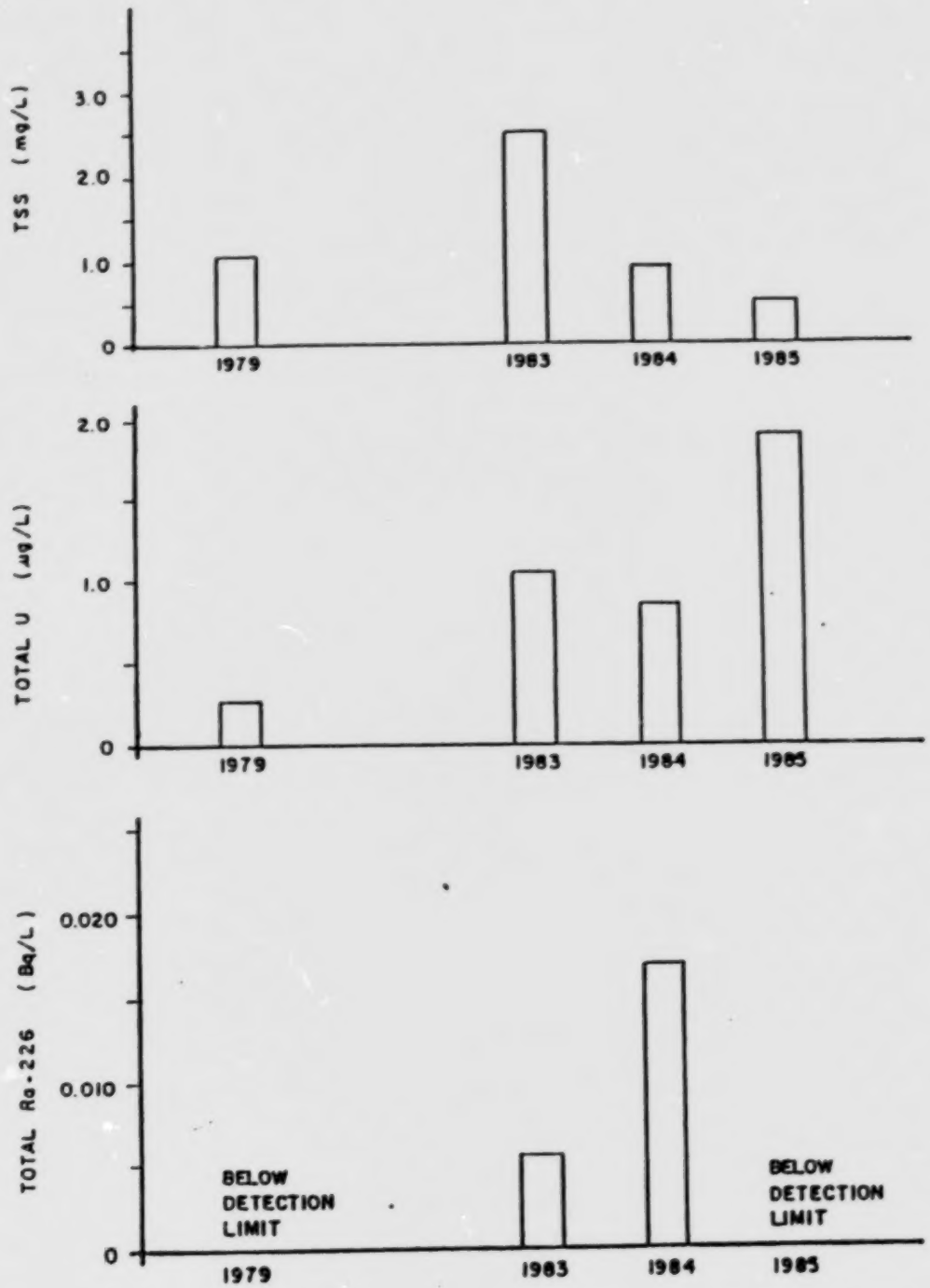

FIGURE 4
TRENDS IN WATER QUALITY
COLLINS BAY B-ZONE
STATION 6.2
(Cameco 1986)

be related to inputs from runoff, which are essentially zero in the winter.

Inputs from runoff are affected by mining activity as well as by the natural geology, topography and vegetation of the drainage basin. To date, there are not enough data to be able to distinguish the effects of mining activity from increased runoff per se. The one year when runoff decreased significantly (1987) saw a corresponding decrease in uranium and arsenic, although not down to baseline levels.

In summary, the spill did not result in any increase in water quality parameters except for uranium. Winter water quality data normally show very low levels of most trace analytes because there is usually zero input in the winter. The change in the normal winter water quality pattern caused by the uranium increase was small and short-lived. Comparisons of the data gathered after the spill with baseline and monitoring data show that trends may be related to volume of runoff, normal fluctuations in background, laboratory accuracy and/or the cumulative effects of exploration, construction and mining activity. There are insufficient data to date to be able to distinguish between the effects of increased runoff per se from the effects of mining activity.

3.2 Sediment Quality

Statistical analysis of radionuclide levels among sediment sampling sites showed that most of the significant differences occurred between the lake sites (sites 3 and 4) and the creek sites that were in swift-flowing areas (sites 1 and 2). Site 3 (mouth of Collins Creek, near the boat dock) had significantly higher levels of uranium and lead-210 than the other sites (Table 7 and Table 8). Sites 3 and 4 (site 4 was from

Table 7. Sediment Analysis Summary For Sites 1-5 (Depth = 1 is 0-5 cm; Depth = 2 is 5-10 cm). Metals and uranium in ug/g dry weight. Radionuclides in Bg/g dry weight.

Variable	N	Mean	Standard Deviation	Minimum Value	Maximum Value	STD Error of Mean
			Site = 1 Depth = 1			
U	3	1.6	0.11	1.5	1.7	0.07
TH230	3	0.02	0.006	0.01	0.02	0.003
RA226	3	0.02	0.01	0.005	0.03	0.007
PO210	3	0.05	0.006	0.04	0.05	0.003
PB210	3	0.06	0.006	0.06	0.07	0.003
AS	3	13.7	2.5	11.0	16.0	1.4
CO	3	6.0	1.0	5.0	7.0	0.5
CR	3	60.3	17.9	45.0	80.0	10.3
NI	3	3.2	2.7	0.5	6.0	1.6
PB	3	9.7	3.2	6.0	12.0	1.9
			Site = 2 Depth = 1			
U	3	1.4	0.06	1.4	1.5	0.03
TH230	3	0.02	0.01	0.01	0.03	0.007
RA226	3	0.02	0.005	0.02	0.03	0.003
PO210	3	0.05	0.006	0.04	0.05	0.003
PB210	3	0.07	0.0	0.07	0.07	0.0
AS	3	31.7	15.7	14.0	44.0	9.1
CO	3	5.3	1.1	4.0	6.0	0.6
CR	3	30.0	7.5	22.0	37.0	4.4
NI	3	1.0	0.8	0.5	2.0	0.5
PB	3	6.0	6.9	2.0	14.0	4.0
			Site = 3 Depth = 1			
U	3	5.7	0.53	5.1	6.1	0.31
TH230	3	0.08	0.06	0.04	0.14	0.03
RA226	3	0.10	0.006	0.1	0.11	0.003
PO210	3	0.37	0.10	0.25	0.45	0.06
PB210	3	0.58	0.03	0.55	0.60	0.02
AS	3	15.0	0.0	15.0	15.0	0.0
CO	3	7.7	0.58	7.0	8.0	0.33
CR	3	21.7	1.5	20.0	23.0	0.88
NI	3	6.7	3.8	4.0	11.0	2.2
PB	3	17.3	2.9	14.0	19.0	1.7
			Site = 3 Depth = 2			
U	3	3.9	0.49	3.6	4.5	0.28
TH230	3	0.03	0.006	0.03	0.04	0.003
RA226	3	0.10	0.01	0.09	0.11	0.007
PO210	3	0.30	0.09	0.2	0.35	0.05
PB210	3	0.43	0.03	0.4	0.45	0.02
AS	3	17.0	0.0	17.0	17.0	0.0
CO	3	9.7	1.2	9.0	11.0	0.67
CR	3	15.0	2.6	13.0	18.0	1.5
NI	3	8.0	7.0	3.0	16.0	4.0
PB	3	21.7	4.0	18.0	26.0	2.3

Site 1 = Above, 2 = Below (immediately), 3 = Boat Club, 4 = Out in lake
5 = Little bay by spill

Table 7. (Continued) (Depth = 1 is 0-5 cm; Depth = 2 is 5-10 cm).

Variable	N	Mean	Standard Deviation	Minimum Value	Maximum Value	STD Error of Mean
			Site = 4 Depth = 1			
U	3	4.6	0.44	4.3	5.1	0.25
TH230	3	0.04	0.006	0.04	0.05	0.003
RA226	3	0.08	0.006	0.07	0.08	0.003
PO210	3	0.32	0.03	0.3	0.35	0.02
PB210	3	0.43	0.03	0.4	0.45	0.02
AS	3	24.3	5.8	20.0	31.0	3.4
CO	3	8.0	1.0	7.0	9.0	0.5
CR	3	19.3	4.0	15.0	23.0	2.3
NI	3	3.3	0.6	3.0	4.0	0.33
PB	3	27.7	2.3	25.0	29.0	1.3
			Site = 4 Depth = 1			
U	3	3.3	0.17	3.2	3.5	0.10
TH230	3	0.04	0.01	0.03	0.05	0.007
RA226	3	0.06	0.02	0.04	0.07	0.01
PO210	3	0.13	0.02	0.11	0.14	0.01
PB210	3	0.15	0.04	0.11	0.19	0.02
AS	3	12.7	0.58	12.0	13.0	0.33
CO	3	10.3	0.58	10.0	11.0	0.33
CR	3	12.0	2.0	10.0	14.0	1.2
NI	3	2.7	0.58	2.0	3.0	0.33
PB	3	16.0	1.0	15.0	17.0	0.58
			Site = 5 Depth = 1			
U	3	4.3	0.26	4.0	4.5	0.15
TH230	3	0.05	0.04	0.03	0.10	0.02
RA226	3	0.07	0.03	0.04	0.09	0.01
PO210	3	0.26	0.08	0.17	0.30	0.04
PB210	3	0.33	0.10	0.25	0.45	0.06
AS	3	10.0	1.00	9.0	11.0	0.58
CO	3	6.0	1.00	5.0	7.0	0.58
CR	3	14.7	5.0	10.0	20.0	2.9
NI	3	6.3	3.0	3.0	9.0	1.8
PB	3	10.0	3.6	6.0	13.0	2.1
			Site = 5 Depth = 2			
U	3	3.6	0.25	3.3	3.0	0.15
TH230	3	0.04	0.01	0.03	0.05	0.006
RA226	3	0.06	0.02	0.05	0.08	0.009
PO210	3	0.14	0.02	0.12	0.16	0.01
PB210	3	0.17	0.02	0.15	0.19	0.01
AS	3	9.0	0.0	9.0	9.0	0.0
CO	3	6.7	0.58	6.0	7.0	0.33
CR	3	26.7	10.5	16.0	37.0	6.1
NI	3	5.3	0.58	5.0	6.0	0.33
PB	3	4.3	4.0	2.0	9.0	2.3

Site 1 = Above, 2 = Below (immediately), 3 = Boat Club, 4 = Out in lake
5 = Little bay by spill

Table 8. Summary of Statistical Analysis of Sediment Radionuclide and Metal Levels Over the Five Sites for the 0-5 cm Core Section.

Element	Site Groupings (From Highest to Lowest Levels; Groupings with Different letter are Significantly Different)	
Uranium	3	A
	4, 5	B
	1, 2	C
Thorium	No Differences	
Radium -226	3, 4	A
	5	B
	1, 2	C
Polonium -210	3, 4, 5	A
	1, 2	B
Lead -210	3	A
	4, 5	B
	1, 2	C
Arsenic	2	A
	1, 3, 4	AB
	5	B
Cobalt	4	AB
	1, 3, 5	AB
	2	C
Chromium	1	A
	2, 3, 4, 5	B
Nickel	No Difference	
Lead	4, 3	A
	1, 3, 5	AB
	2	C
Aluminum	3, 4, 5	A
	1, 2	B

mid-bay) had significantly higher radium-226 levels than sites 1,2 and 5. Sites 3,4 and 5 (site 5 was the backwater area in Collins Creek) had significantly higher polonium-210 levels than sites 1 and 2. There were no differences in thorium-230 levels among any of the sites.

In general, the lake sites were higher than the creek sites. This is to be expected because the lake sites are in depositional areas whereas the creek sites 1 and 2 are in areas where little settling out can occur. Site 5 in Collins Creek is a depositional area as it is a backwater; this was reflected in the higher polonium-210 levels.

Statistical analysis of metal levels did not show the same consistent division between depositional and flowing environments as had been observed for the radionuclides. For example, arsenic levels were highest at site 2 and lowest in site 5, the opposite of what might be expected. Sites 1,2,3 and 4 were not significantly different from each other (Tables 7 and 8). In contrast to having the highest arsenic levels, site 2 had the lowest levels of cobalt and lead while site 4 had the highest levels of cobalt and lead. There was only one significant difference for chromium; site 1 had significantly higher levels than all other sites. There were no significant differences in nickel levels among sites. Aluminum was the only metal that was consistently higher in the depositional sites (3-5).

Comparison between the top layer of sediment with lower layers should indicate whether deposition of radionuclides and metals has increased in recent times. Unfortunately, it was logistically impossible to obtain very thin samples of the first mm or less of sediment that would be clearly associated with the spill event. Instead, the sediment data consist of the top 0-5 cm layer and the lower layer. This

hampers interpretation of the effect of the spill per se on sediment levels.

The only sites where the corer could penetrate far enough to obtain a layer below 5 cm were sites 3-5. Statistical analysis of the combined depth data for sites 3-5 showed that the top layer was higher in uranium, polonium-210 and lead-210 (Table 9). Analysis for sites 3, 4 and 5 individually showed more differences with depth than the overall analysis because of the smaller variances in the data sets (Table 10). Uranium was higher in the top layer at all three sites. The top layer at site 4 had higher levels of most of the radionuclides and metals with the exception of thorium-210, radium-226 and nickel. Lead-210 and chromium were higher in the top layer at site 3. The only element that was higher in the lower layer was arsenic at site 3.

Sedimentation rates are generally low in oligotrophic lakes. For example, pre-European settlement sedimentation rates in the Bay of Quinte, Lake Ontario were 0.38 mm/yr (Warwick 1980). Sedimentation rates increase in response to settlement, agriculture, industrialization or deforestation. Thus, rates in the Bay of Quinte increased to 2.7 mm/yr in the early colonial period and were as high as 41.3 mm/yr during a period of deforestation. Collins Bay sedimentation rates have likely been somewhat lower than pre-European Bay of Quinte rates since the Bay of Quinte is part river and part bay. Increases in sedimentation would be caused by forest fires or disturbance caused by exploration and development of the mine.

Even if sedimentation rates have increased in response to mine exploration and development, the 0-5 cm section taken as "surface" sediments probably represents many years of deposition, including the years

Table 9. Summary of Differences between depths for Sites 3-5 Lumped together.

U	1 & 2 different (1 the highest)
Th-230	no difference
Ra-226	no difference
Po-210	1 & 2 different (1 the highest)
Pb-210	1 & 2 different (1 the highest)
As	no difference
Co	1 & 2 different (2 the highest)
Cr	no difference
Ni	no difference
Pb	no difference

Table 10. Summary of Differences between Depths for Site 3.

U	1 & 2 different (1 the highest)
Th-230	no difference
Ra-226	no difference
Po-210	no difference
Pb-210	1 & 2 different (1 the highest)
As	1 & 2 different (2 the highest)
Co	no difference
Cr	1 & 2 different (1 the highest)
Ni	no difference
Pb	no difference

Summary of Differences between Depths at Site 4

U	1 & 2 different (1 the highest)
Th-230	no difference
Ra-226	no difference
Po-210	1 & 2 different (1 the highest)
Pb-210	1 & 2 different (1 the highest)
As	1 & 2 different (1 the highest)
Co	1 & 2 different (1 the highest)
Cr	1 & 2 different (1 the highest)
Ni	no difference
Pb	1 & 2 different (1 the highest)

Summary of differences between depths for Site 5

U	1 & 2 different (1 the highest)
Th-230	no difference
Ra-226	no difference
Po-210	no difference
Pb-210	no difference
As	no difference
Co	no difference
Cr	no difference
Ni	no difference
Pb	no difference

of exploration and development (1978-to present). The increased deposition of uranium and some other elements in the top sediment layer may be a result of drilling and construction of the B-zone pit. A core collected in the vicinity of a drilling site in Collins Bay in 1979 had radionuclide levels that were above background in the top 5 cm (Neame et al 1982). The authors concluded that exploratory drilling may cause significant radionuclide releases throughout the exploration area. This helps explain the higher levels in the surface sediments at sites 3 and 4. The causes of higher deposition at site 5 is more difficult to interpret. It may be related to the increased runoff over the 1983-86 period compared to the low runoff previous to those years. There are probably several causes that are related to each other; for example, increased runoff from areas that have been affected by background geology, exploration, road construction and mining activity.

Although radionuclides are known to be rapidly removed to the sediments (Hesslein and Slavicek 1984), it has been found that the flux of radionuclides from sediments back into the water column can also be quite rapid (Waite et al 1989). Release rates of 0.5 Bq lead-210 and 5.7 Bq radium-226 per m^2/hr were observed in the contaminated sediments of Langley Bay in Lake Athabasca (Waite et al 1989). Therefore, the increased uranium levels in Collins Bay water in 1983-86 may reflect release from sediments which in turn had higher levels because of background geology, exploration and construction.

Comparison of the sediment data obtained for this study with baseline data for Collins Creek and Collins Bay is difficult due to the lack of radionuclide baseline data. Metal baseline data indicate that the

post-spill sediment sample results are within the range recorded before mining development (Table 11).

Comparison of the post-spill data with monitoring data shows that radionuclides were lower post-spill than in the year of the construction of the B-zone pit (1984) or the following year (1985) (Table 11). Arsenic and nickel in the post-spill samples were within the range reported for similar sites in 1985. Lead in the post-spill samples was lower than in 1985.

Comparison of the Collins Bay data with data from other locations indicates that the sediment radionuclide levels were similar or somewhat lower than sediments in Cluff Lake with high organic content (Table 11). The Collins Creek sediment samples had similar radionuclide levels to those noted for Cluff Lake sediments with very low organic content (Table 11). Beaverlodge Lake sediments had radionuclide levels that were an order of magnitude higher than those noted in this study, reflecting the effects of an old-style uranium mining operation on Beaverlodge Lake, plus the background geology of the area. Metal levels in Beaverlodge Lake sediments were also generally higher than in this study.

In general, the comparisons indicate that the post-spill Collins Creek and Collins Bay radionuclide and metal levels were either similar to or somewhat lower than those in earlier monitoring studies. Furthermore, the radionuclide and trace element levels seen in the sediments from all sites are within the background levels that have been recorded at other uranium mining locations. They are lower than those seen in a lake that was affected by an older uranium mine without environmental controls (Beaverlodge Lake). Organic content and texture of the sedi-

Table 11. Comparison of Post-Spill Surface Sediment Data With Baseline and Monitoring Data and With Other Locations (in ug/g dry weight except where indicated).

Location	Source	Data Type	Year	Uranium	Radium -226 Bq/g	Lead -210 Bq/g	Polonium -210 Bq/g	Thorium -230 Bq/g	Arsenic	Nickel	Cobalt	Chromium	Lead	LOI	Manganese	Iron
Collins Creek Upstream	A	Post-spill	1989	1.6	0.02	0.06	0.05	0.02	13.7	3.2	6	60.3	9.7	2.5	2,130	50,667
Collins Creek Downstream	A	Post-spill	1989	1.4	0.03	0.08	0.05	0.02	31.7	1.0	5.3	30.0	6.0	3.6	1,400	58,333
Collins Creek Mouth	A	Post-spill	1989	5.7	0.10	0.58	0.37	0.08	15.0	6.7	7.7	21.7	17.3	23.0	1,300	59,667
Collins Bay By B-Zone	A	Post-spill	1989	4.6	0.08	0.43	0.32	0.04	24.3	3.3	8.0	19.3	27.7	16.9	1,800	55,000
Collins Creek Backwater	A	Post-spill	1989	4.2	0.07	0.33	0.26	0.05	10.0	6.3	6.0	14.7	10.0	28.9	363	33,333
Collins Bay	B	Baseline	1973	—	—	—	—	—	—	11.0	6.0	33.0	4.0	—	5,600	65,000
Collins Bay	C	Baseline	1979	—	—	—	—	—	244.0	32	21	49	160	15.4	3,200	56,000
Collins Creek	D	NUTP Study	1984	5.7	0.12	—	—	—	—	—	—	—	—	0.8	240	7,100
Collins Bay	D	NUTP Study	1984	6.1	0.08	—	—	—	—	—	—	—	—	18	3,800	6,700
Pow Bay	D	NUTP Study	1984	8.8	0.07	—	—	—	—	—	—	—	—	6.7	5,800	16,000
Hidden Bay	D	NUTP Study	1984	11.5	0.13	—	—	—	—	—	—	—	—	17	5,300	39,200
Pow Bay	E	Monitoring	1986	4.2	0.04	<0.2	0.09	0.02	1.5	12	—	—	26	1.5	—	2.1%
Cluff Lake S.	F	EIS	1979	17	0.27	0.15	0.09	—	11.1	27	26	41	11.1	35.6	559	199,000
Cluff Lake N.	F	EIS	1979	0.04	0.01	0.06	0.09	—	0.13	0.43	1.1	3.3	1.3	0.21	42	629
Beaverlodge L.	G	Research	1981	139	1.21	2.01	—	—	—	31.1	14.6	41.6	210.3	9.9	2,233	26,667

Table 11. (Continued)

Location	Source	Data Type	Year	Uranium	Radium -226 Bq/g	Lead -210 Bq/g	Polonium -210 Bq/g	Thorium -230 Bq/g	Arsenic	Nickel	Cobalt	Chromium	Lead	LOI	Manganese	Iron
Collins Bay	H	Monitoring	1984													
Collins Creek Mouth				9.9	0.14	0.93	—	—	—	—	—	—	—	—	—	—
Opp. B-zone				18	0.82	0.94	—	—	—	—	—	—	—	—	—	—
Collins Bay	I	Monitoring	1985													
E. of B-zone				11.3	0.13	0.30	—	—	31.3	10	—	—	28	10.9	—	—
W. of B-zone				6.4	0.09	0.41	—	—	19.1	8	—	—	31	14.9	—	—

A. This study
B. Sawchyn 1973
C. Gulf 1980
D. NUTP 1985
E. Cameco 1986
F. Cluff Mining 1979
G. Swanson 1985
H. Cameco 1984
I. Cameco 1985

ment and the presence of iron and manganese are related to radionuclide and metal levels in the Wollaston area (Mellinger 1989); the effects of these factors helps explain the variation among sites in Collins Creek and Collins Bay.

In summary, the comparison of surface sediment and lower-layer sediment data indicates increased uranium in the surface sediments across all sites that are in depositional areas. There were also increases in some other elements, although these were not consistent across all sites. Because this increase is seen at the site that is the most remote from the spill path as well as closer sites, it is likely that the cause of this increase is related to factors other than an isolated spill event. This is confirmed by monitoring data from 1984-85 where the effects of construction of the B-zone appear evident in radionuclide levels. If the 0-5 cm section taken as the "surface" sediment fraction in this study includes sediments that were laid down in 1978-89, the increased levels in the surface are most likely due to background geology, exploration and construction activity.

3.3 Fish Radionuclide and Metal Levels

3.3.1 Fish Radionuclide Levels

Radionuclide and metal levels in fish collected in this study are summarized in Table 12. Radionuclide levels are uniformly low in both species.

Differences in radionuclide accumulation between flesh and bone cannot be discussed in most cases because the results for both were below detection limits. The exception is uranium, where bone generally had higher levels than flesh. This is in line with the results of other studies where radionuclide levels are generally highest in bone (Swanson 1985).

Bioaccumulation factors (BFs) in fish from this study are shown in Table 13. Radium-226 and lead-210 BFs are generally within the literature BFs of 1-600 for flesh and 30-650 for bone. Polonium-210 and thorium-230 BFs are not as common in the literature; 50 has been recommended as the BF for polonium-210 in food chain models and 30 as the BF for thorium (Zach 1982). The polonium-210 BFs in this study are higher than 50; the thorium BFs for bone are slightly greater than 30. Uranium BFs in this study are generally higher than has been noted in the literature, and are higher than those noted for Beaverlodge Lake.

The significance of BFs is that they can indicate the extent to which fish accumulate radionuclides in a given environment, thus making the radionuclides available for transfer up the food chain. The results of this study show that for radium-226, lead-210 and thorium, the BFs are similar to overall means from other studies; therefore, the food chain transfer will not be any greater in Wollaston Lake than elsewhere. Uranium and polonium-210 have higher BFs than have been generally Table

Table 12. Summary of Fish Analysis for this study (means in micrograms per gram wet weight ± standard deviation). Sample size = 5 per species per tissue.

Element	Lake Whitefish				Longnose Sucker			
	Flesh		Bones		Flesh		Bones	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Aluminum	6.1	3.2	17.9	3.2	7.4	5.1	9.1	1.3
Arsenic	0.33	0.33	0.22	0.10	0.30	0.05	0.07	0.03
Chromium	<0.4	0.0	<0.3	0.0	<0.35	0.0	<3.0	0.00
Copper	2.8	3.2	1.0	0.74	2.2	1.3	0.51	0.01
Nickel	<0.39	0.06	<0.94	1.1	<0.48	0.20	<0.26	0.009
Lead -210	<0.001	0	<0.003	0.003	0.001	0.0004	0.012	0.02
Polonium -210	<0.0005	0.0002	0.001	0.0007	0.002	0.002	0.002	0.002
Radium -226	<0.00009	0.00001	0.0007	0.00007	<0.00007	0.00001	<0.002	0.003
Thorium -230	<0.0002	0	0.0014	0.0003	<0.0001	0.00006	<0.0017	0.0002
Uranium	0.007	0.003	0.08	0.02	0.01	0.02	0.20	0.37

Table 13. Bioaccumulation Factors for Collins Bay Fish Radionuclides

Element	Lake Whitefish		Longnose Sucker	
	Flesh	Bone	Flesh	Bone
Lead-210	<50	<150	<50	<60
Polonium-210	<100	<200	400	400
Radium-226	<18	<140	14	400
Thorium-230	<7	<47	<3	<56
Uranium	97	1,140	143	2,857

reported in the literature. This indicates that these two radionuclides are more available for uptake in the Collins Bay environment; however, sample sizes were very small in this study so a firm conclusion is not possible. Because initial radionuclide levels in the sources (water and sediments) are comparatively low, radionuclide levels in the fish in Collins Bay are low as well, even with higher-than-average BFs for uranium and polonium.

The dose to humans from eating the fish from Collins Bay can be estimated by taking the fish radionuclide levels, assuming a certain average fish intake by people and converting this to dose equivalents. When it was assumed that a 500 g serving of whitefish from Collins Bay was consumed once per week for a year, the estimated weighted committed dose equivalent was 3.6×10^{-5} Sieverts. The annual dose limit for the general public is 0.005 Sieverts. Therefore, the weekly consumption of Collins Bay whitefish would result in 0.7% of the annual dose limit. This is not a significant contribution to dose; it is at background levels recorded from control, uncontaminated lakes in the Uranium City area.

Comparison of the post-spill fish data with previous monitoring data and data from other locations indicates that the radionuclides in the post-spill fish samples were within the range reported for previous monitoring and were similar to baseline data collected at several other Saskatchewan lakes (Tables 15-28). Therefore, there is no indication that the spill resulted in an increase in radionuclide levels in Collins Bay fish. The sample size in this study was small; the chances of detecting what would be an extremely subtle difference in fish radionuclide levels as a result of one spill event with such a sample size

are miniscule. The fish sample from this study most likely reflects the cumulative effect of the ongoing mining activity adjacent to Collins Bay.

In summary, post-spill fish samples did not have elevated radionuclide levels. Bioaccumulation factors were within literature values except for uranium and polonium BFs, which were slightly higher. Doses to people from regular consumption of Collins Bay fish would be negligible. There was no evidence that the spill caused any increase in fish radionuclide levels.

3.3.2 Fish Metal Levels

Table 12 summarizes the data for metals that appeared in detectable amounts in the Collins Bay fish. Aluminum, copper and arsenic had the highest levels; nickel was usually very close to or below detection limits.

The relationship between flesh and bone levels for metals varied. Bones had higher aluminum levels. Flesh had higher copper levels. Arsenic and nickel levels were so low that Consistent patterns were not discernible for arsenic and nickel levels.

Levels of metals in the post-spill fish samples showed differences with previous monitoring data and with data from other northern Saskatchewan lakes. Arsenic and copper levels were higher in the post-spill samples (Tables 15-28). The differences are quite great; the spill samples were an order of magnitude higher. When the standard deviations of the post-spill samples are considered, there are still differences apparent. The lakes that are most similar to the post-spill samples are

those in the Midwest area (South McMahon Lake). This similarity is for copper levels; arsenic is low in fish from the Midwest area.

There are no Canadian limits for arsenic in fish (Houston pers. comm.). The average dietary intake of arsenic for Canada, the United Kingdom, the United States and France was 25-33 ug/day from the ingestion of food and water (Marchant et al. 1988). Arsenic in shellfish and other marine foods is extensively absorbed and rapidly excreted intact as a complex organoarsenical and does not appear to be a health threat to humans (Marchant et al.1988). Therefore, the levels of arsenic in Collins Bay fish should not be of concern in terms of human consumption.

The range of copper in freshwater fish muscle in Canada has been reported to range between 0.5 and 1.4 ug/g wet weight (Spear and Pierce 1979). Collins Bay fish levels are slightly higher than these average levels (Table 12). Copper is an essential trace nutrient for humans. The levels in the Collins Bay fish are not of concern in terms of human consumption (Houston pers. comm.).

In summary, arsenic and copper levels in the post-spill fish were higher than background or monitoring data. Copper levels were also higher than average levels in Canadian food. There are no Canadian limits for arsenic or copper in fish. Arsenic in seafood is rapidly absorbed and then rapidly excreted intact as an organoarsenical; therefore the levels of arsenic in Collins Bay fish should not be of concern. Copper is an essential trace nutrient for humans; the levels in Collins Bay fish are not of concern with respect to human consumption.

3.3.3 Causes of Increased Metal Levels in Collins Bay Fish

The small size of the monitoring database for fish from Collins Bay and the lack of good information on standard deviations of monitoring samples makes it very difficult to interpret the post-spill data. The fish from the post-spill study were all collected from the area around the mouth of Collins Creek. The surface sediments in this area had higher uranium levels; however, the metals were not noticeably increased over background or over previous monitoring. Water quality from this area also had slightly elevated uranium levels for a short period but metals were not significantly different from previous monitoring. The cause of the higher arsenic and copper levels in the post-spill fish sample is probably more related to the ongoing cumulative effects of the mining operation plus the natural geology of the area than to the spill event.

4 CONCLUSIONS

4.1 Effects of the Minewater Spill

(1) Uranium was the only water quality parameter to show an increase in the aftermath of the spill; this increase was small and of short duration.

(2) There were no observed increases in sediment radionuclides or metals caused by the spill.

(3) Fish radionuclide levels in the samples taken after the spill were not distinguishable from background.

(4) The dose to people from eating fish from Collins Bay once a week for a year would be 0.7% of the annual dose limit for the general public; this is not a significant dose.

4.2 Other Trends Noted in the Data

(1) Increasing trends in some water quality parameters observed from examining monitoring data may be related to fluctuations in runoff as well as to effects of background geology, exploration, construction and mining operations adjacent to Collins Bay.

(2) There have been increases in uranium, lead-210 and some metals in surface sediments compared to lower sediment layers; this surface layer probably represents years when sediment levels were affected by exploration and construction of the B-zone, although increases in some depositional areas in Collins Creek are more difficult to interpret.

(3) Arsenic and copper levels in the post-spill fish samples were greater than background or monitoring samples and were also greater than

most levels recorded for fish in other northern Saskatchewan lakes; however, the arsenic and copper levels measured are not of concern with respect to human consumption.

(4) The causes of the greater arsenic and copper levels in Collins Bay fish are unknown; it is unlikely that the spill caused these increases because water quality and sediment quality data did not show significant increases in these parameters after the spill.

5 RECOMMENDATIONS

Several of the trends noted in the data listed in the Conclusions require follow-up investigation. In addition, there is a lack of monitoring data for sediments and fish in Wollaston Lake (especially for Collins Bay). Because of lack of replication, the monitoring data that do exist lack information on the natural variability in radionuclide and metal levels. This hampers attempts to draw conclusions based upon data from studies such as this one. Therefore, I recommend that the following studies be conducted.

(1) Trends in water quality parameters should continue to be monitored closely in Collins Bay. These water quality data should be accompanied by information on annual runoff and should be related to precise information on any exploration or construction activity taking place in or adjacent to Collins Bay each year as well as to a compilation of information on background geology of the Collins Bay watershed.

(2) Radionuclides and metals in Collins Bay sediments should be monitored at several sites ranging out from the mouth of Collins Creek and including sites near the B-zone. This monitoring should include collection of replicate samples at each site for each sampling time. Replication allows estimation of natural variation in radionuclide and metal levels at each site. Knowledge of variation at each site then enables one to statistically examine differences among sites and sampling times. The samples should be cores rather than grabs and should be divided into sections for separate analysis of upper and lower sediment layers. These data could then be used to confirm the increases in uranium, lead-210 and some metals observed in this study as well as to document any trends that may be present over time. Information on

exploration and mining activity should accompany these data, as has been recommended for the water quality data. This will aid interpretation of results.

(3) A study of fish in early spring of 1990 at the mouth of Collins Creek is needed to confirm that radionuclide levels remain at background in the aftermath of the spill. This early spring study will indicate whether there are any delayed accumulations of radionuclides through the food chain because of the spill. Early spring will coincide with the period when fish resume active feeding. The same two species of fish collected in this study should be collected in the spring. Sample sizes should also be the same. Samples should be analysed for both radionuclides and metals.

(4) The sources of increased arsenic and copper in the fish from Collins Bay should be investigated. This will include examination of data obtained from the study recommended in (3) to confirm that the levels are still elevated. Information on background geology of the area should be thoroughly examined, especially regarding the source of copper. Possible pathways for arsenic into Collins Bay should be investigated, especially regarding the possible relationship between exploration, construction and mining activity and increased inputs of elements associated with the ore into the Bay.

Table 14. Summary of Fish Metals Data: For Collins Bay and Other N. Saskatchewan Locations: Whitefish 1972 to 1989.

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake															
Collins Bay	1989	A	Flesh	6.1	3.2	0.33	0.33	<0.4	0.0	2.8	3.2	<0.39	0.06	—	—
		A	Bone	17.9	3.2	0.22	0.10	<0.3	0.0	1.0	0.74	<0.94	1.1	—	—
	1984	D	Flesh	—	—	—	—	0.21	0	0.24	0	0.14	0	0.04	0
		D	Bone	—	—	—	—	1.3	0	0.5	0	0.56	0	0.62	0
	1972	E	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		E	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Hidden Bay	1984	D	Flesh	—	—	—	—	0.51	0.69	0.21	0.06	1.26	2.03	0.05	0.01
		D	Bone	—	—	—	—	0.92	0.13	0.41	0.01	0.58	0.54	0.67	0.06
	1972	E	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		E	Bone	—	—	—	—	—	—	—	—	—	—	—	—
S. McMahon Lake	1988	F	Flesh	—	—	0.0002	0.00007	0.12	0.07	0.22	0.04	0.05	0.04	—	—
		F	Bone	—	—	0.003	0.0001	1.37	0.9	0.6	0.36	0.23	0.22	—	—
	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	<0.1	—	—	—
Mink Arm	1988	F	Flesh	—	—	—	—	0.05	0.007	0.42	0.17	0.05	0.02	—	—
		F	Bone	—	—	0.008	0.003	0.97	0.83	0.64	0.15	0.53	0.11	—	—
N. McMahon Lake	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.2	—	—	—
		G	Flesh	—	—	<0.01	—	—	—	—	—	<0.1	—	—	—
Henday Lake	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.4	—	—	—
Hatchet Lake															
Smith Bay	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.3	—	—	—
Waterbury Lake															
Nicholson Bay	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	<0.1	—	—	—
Shallow Lake	1979	G	Flesh	—	—	0.01	—	—	—	—	—	<0.1	—	—	—
McLaan Lake	1980	I	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1979	H	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
	1979	G	Flesh	—	—	<0.1	—	—	—	—	—	0.2	—	—	—

Table 14. (continued)

Location	Date	Source Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Dawn Lake	1983	N	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		N	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1982	J	Whole (gutted)	—	—	—	—	—	—	—	—	—	—	—	—
	1981	J	Whole (gutted)	—	—	—	—	—	—	—	—	—	—	—	—
Thor Lake	1988	K	Flesh	0.12	0.16	0.01	0.009	<0.02	0	<0.02	0	<0.02	0	—	—
		K	Bone	0.667	0.58	0.05	0.03	0.16	0.02	0.16	0.02	0.16	0.02	—	—
Beaverlodge Lake	** 1983	L	Whole	0.07	0.08	—	—	0.008	0.01	0.015	0.008	—	—	—	—
	** 1982	M	Skin	—	—	—	—	—	—	—	—	—	—	—	—
		M	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		M	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Fredette Lake	** 1983	L	Whole	0.05	0.03	—	—	0.006	0.002	0.02	0.008	—	—	—	—
	*** 1982	M	Skin	—	—	—	—	—	—	—	—	—	—	—	—
		M	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		M	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Milliken Lake	** 1983	L	Whole	0.10	0.2	—	—	0.007	0.004	0.02	0.01	—	—	—	—
	*** 1982	M	Skin	—	—	—	—	—	—	—	—	—	—	—	—
		M	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		M	Bone	—	—	—	—	—	—	—	—	—	—	—	—

* A = This Study
B = Cameco 1988
C = Cameco 1986
D = Sask Environment 1984
E = Sawchyn 1973
F = Senes 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984
O = Waite et al. 1988

** Average of 60% used to convert metals data from dry weight to wet weight.
*** Standard error recorded in place of standard deviation.

Table 15. Summary of Fish Radionuclide Data: For Collins Bay and Other N. Saskatchewan Locations: Whitefish 1972 to 1989.

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U Bq/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake Collins Bay	1989	A	Flesh	<0.001	0	<0.0005	0.0002	<0.00009	0.00001	<0.0002	0	0.007	0.003
		A	Bone	<0.003	0.003	0.001	0.0007	0.0007	0.00007	0.001	0.0003	0.08	0.02
	1984	D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
	1972	E	Flesh	0.0003	0	0.0001	0	0.0001	0	—	—	0.007	0.0009
		E	Bone	0.0036	0	0.0007	0	0.0007	0	—	—	0.039	0
Hidden Bay	1984	D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
	1972	E	Flesh	0.0003	0	0.0001	0	0.0001	0	—	—	0.05	0.001
		E	Bone	0.004	0	0.0007	0	0.0008	0.0001	—	—	0.40	0.007
S. McMahon Lake	1988	F	Flesh	0.0004	0.00008	—	—	0.00007	0.00006	—	—	<0.1	—
		F	Bone	<0.02	—	—	—	0.001	0	—	—	0.0144	0
	1979	G	Flesh	<0.004	—	—	—	<0.004	—	—	—	—	—
Mink Arm	1988	F	Flesh	<0.02	—	—	—	0.00004	0.00002	—	—	<0.1	—
		F	Bone	0.028	0.0014	—	—	0.0028	0	—	—	0.07	0.01
N. McMahon Lake	1979	G	Flesh	<0.0004	—	—	—	0.01	—	—	—	—	—
		G	Flesh	<0.0004	—	—	—	0.02	—	—	—	—	—
Henday Lake	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
Hatchet Lake . Smith Bay	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
Waterbury Lake Nicholson Bay	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
Shallow Lake	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
M Lean Lake	1980	I	Bone	0.008	0.008	—	—	0.0009	0.0004	—	—	0.040	0.003
	1979	H	Flesh	—	—	—	—	0.0001	0	—	—	0.0009	0.0004
	1979	G	Flesh	<0.0004	—	—	—	—	—	<0.0004	—	—	—

Table 15. (continued)

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U uq/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
Dawn Lake	1983	N	Flesh	0.0001	0	—	—	0.0001	0	—	—	0.003	0.0005
		N	Bone	0.004	0.001	—	—	0.001	0.0005	—	—	0.04	0
	1982	J	Whole (gutted)	0.0007	0	0.0002	0	0.0003	0.0001	—	—	0.01	0.0027
	1981	J	Whole (gutted)	0.0007	0	0.0002	0	0.00034	0.00021	—	—	0.02	0.00892
Thor Lake	1988	K	Flesh	0.001	0.001	—	—	0.0001	0	0.0002	0	0.004	0.0003
		K	Bone	0.004	0.0005	—	—	0.0014	0.0005	0.0017	0.0003	0.02	0.002
Beaverlodge Lake **	1983	L	Whole	—	—	—	—	—	—	—	—	—	—
***	1982	M	Skin	0.004	0.0004	—	—	0.005	0.001	—	—	1.94	0.37
		M	Flesh	0.001	0.0004	—	—	0.0002	0.0001	—	—	0.08	0.02
		M	Bone	0.04	0.01	—	—	0.03	0.01	—	—	13.16	1.76
Fredette Lake **	1983	L	Whole	—	—	—	—	—	—	—	—	—	—
***	1982	M	Skin	0.002	0.0002	—	—	0.0008	0.0001	—	—	0.25	0.07
		M	Flesh	0.0005	0.0002	—	—	0.0004	0.0002	—	—	0.01	0.002
		M	Bone	0.007	0.001	—	—	0.0004	0.001	—	—	1.09	0.41
Milliken Lake **	1983	L	Whole	—	—	—	—	—	—	—	—		
***	1982	M	Skin	0.004	0.002	—	—	0.0006	0.0002	—	—	0.10	0.02
		M	Flesh	0.0004	0.0001	—	—	0.0002	0.0001	—	—	0.006	0.002
		M	Bone	0.008	0.001	—	—	0.0039	0.0001	—	—	0.55	0.09
Lake Athabasca Langley Bay	1983	O	Flesh	0.004	—	—	—	0.004	—	—	—	0.05	—
		O	Bone	0.15	—	—	—	0.18	—	—	—	1.7	—

* A = This Study
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H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984
O = Waite et al. 1983

** Average of 60% used to convert metals data from dry weight to wet weight.
*** Standard error recorded in place of standard deviation.

Table 16. Summary of Fish Metals Data: For Collins Bay and Other N. Saskatchewan Locations: Northern Pike 1972 to 1988.

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake Collins Bay	1988	B	Flesh	—	—	0.02	0.01	—	—	0.21	0.02	0.7	0.3	—	—
		B	Bone	—	—	0.04	0.02	—	—	0.4	0.2	0.7	0.6	—	—
	1986	B	Flesh	—	—	0.002	—	—	—	0.20	—	0.09	—	—	—
		B	Bone	—	—	0.02	—	—	—	0.28	—	0.06	—	—	—
	1984	B	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		B	Bone	—	—	—	—	—	—	—	—	—	—	—	—
		C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
		D	Flesh	—	—	—	—	0.20	0.17	0.22	0.04	0.08	0.05	0.04	0.01
		D	Bone	—	—	—	—	1.21	0.56	0.45	0.01	2.46	1.50	0.86	0.15
	1979	B	Flesh	—	—	<0.05	—	—	—	1.1	1.0	0.31	0.21	—	—
		B	Bone	—	—	<0.05	—	—	—	1.1	1.0	0.31	0.21	—	—
		C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1972	E	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		E	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Hidden Bay	1988	B	Flesh	—	—	0.04	0.02	—	—	0.2	0.1	0.06	0.03	—	—
		B	Bone	—	—	0.03	0.01	—	—	0.2	0.1	0.4	0.2	—	—
	1986	B	Flesh	—	—	0.002	—	—	—	0.21	—	0.07	—	—	—
		B	Bone	—	—	0.013	—	—	—	0.29	—	0.08	—	—	—
	1984	D	Flesh	—	—	—	—	0.12	0.06	0.24	0.12	0.06	0.02	—	—
		D	Bone	—	—	—	—	0.57	0.13	0.49	0.17	0.19	0.10	0.05	0.02
		C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1982	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1981	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1980	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
		B	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		B	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1972	E	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		E	Bone	—	—	—	—	—	—	—	—	—	—	—	—

Table 16. (Continued)

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Pow Bay	1988	B	Flesh	—	—	0.03	0.01	—	—	0.2	—	0.02	0.03	—	—
		B	Bone	—	—	0.04	0.01	—	—	0.2	0.1	0.3	—	—	—
	1984	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1982	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1981	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1980	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
		B	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		B	Bone	—	—	—	—	—	—	—	—	—	—	—	—
S. McMahon Lake	1988	F	Flesh	—	—	0.0001	0.00002	0.20	0.19	0.29	0.12	0.15	0.15	—	—
		F	Bone	—	—	0.0045	0.0009	1.72	0.07	0.58	0.09	<1.0	—	—	—
	1979	G	Flesh	—	—	<0.01	—	—	—	0.49	—	<0.1	—	—	—
Mink Arm	1988	F	Flesh	—	—	0.0007	0.0003	0.10	0.05	0.16	0.03	0.03	0.02	—	—
		F	Bone	—	—	0.00	0.00	1.27	0.39	0.46	0.02	0.24	0.18	—	—
N. McMahon Lake	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	<0.1	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	0.49	—	<0.1	—	—	—
		G	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Henday Lake	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.2	—	—	—
	1978	G	Flesh	—	—	<0.01	—	—	—	0.37	0.04	0.1	0	—	—
Hatchet Lake Smith Bay	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.2	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	0.36	—	0.2	—	—	—
		G	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Waterbury Lake Nicholson Bay	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	1	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	0.66	0.05	<0.1	0	—	—
		G	Bone	—	—	—	—	—	—	—	—	—	—	—	—

Table 16. (Continued)

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Lake W1	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.1	0	—	—
Shallow Lake	1979	G	Flesh	—	—	—	—	—	—	—	—	<0.1	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	0.42	0.09	0.2	0.07	—	—
		G	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Lake C1	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.2	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	0.33	—	<0.1	—	—	—
			Bone	—	—	—	—	—	—	—	—	—	—	—	—
McLean Lake	1979	G	Flesh	—	—	<0.01	0	—	—	—	—	0.3	0.3	—	—
		G	Bone	—	—	—	—	—	—	—	—	—	—	—	—
		H	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
Dawn Lake	1983	N	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		N	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1982	J	Whole (gutted)	—	—	—	—	—	—	—	—	—	—	—	—
	1981	J	Whole (gutted)	—	—	—	—	—	—	—	—	—	—	—	—
Thor Lake	1988	K	Flesh	0.04	0.04	0.0012	0.0002	0.02	0.001	0.02	0.001	0.02	0.001	—	—
		K	Bone	0.18	0.01	0.02	0.001	0.18	0.01	0.18	0.001	0.18	0.01	—	—

* A = This Study
B = Cameco 1988
C = Cameco 1986
D = Sask Environment 1984
E = Sawchyn 1973
F = Senes 1988
G = Beak 1980
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M = Swanson 1985
N = MacLaren 1984
O = Waite et al. 1988

Table 17. Summary of Fish Radionuclide Data: For Collins Bay and Other N. Saskatchewan Locations: Northern Pike 1972 to 1988.

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake													
Collins Bay	1988	B	Flesh	≤0.02	—	≤0.001	—	≤0.0001	—	≤0.0007	—	≤0.002	—
		B	Bone	≤0.002	—	≤0.001	—	≤0.001	—	≤0.020	—	<0.020	—
	1986	B	Flesh	≤0.01	—	0.002	—	≤0.0004	—	≤0.0004	—	≤0.001	—
		B	Bone	0.01	—	0.003	—	0.0024	—	≤0.0004	—	0.002	—
	1984	B	Flesh	≤0.005	—	—	—	≤0.005	—	≤0.020	—	≤0.010	—
		B	Bone	0.0053	—	—	—	≤0.005	—	≤0.020	—	0.020	—
		C	Flesh	<0.005	—	—	—	<0.005	—	<0.2	—	<0.01	—
		C	Bone	0.005	—	—	—	<0.005	—	<0.2	—	<0.02	—
		D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
	1979	B	Flesh	≤0.002	—	≤0.007	—	≤0.0007	—	≤0.0002	—	≤1	—
		B	Bone	≤0.008	—	—	—	0.0004	0.3	≤0.0004	—	≤3	—
		C	Flesh	<0.0003**	—	—	—	<0.00004	—	—	—	≤0.1	—
				0.001	—	—	—	0.00007	—	—	—	—	—
		C	Bone	0.003**	—	—	—	<0.0001**	—	—	—	<0.3	—
				0.008	—	—	—	0.0007	—	—	—	—	—
	1972	E	Flesh	0.0002	0	0.0001	0	0.0001	0	—	—	0.005	0.0018
		E	Bone	0.004	0	0.0007	0	0.0007	0	—	—	0.04	0.0001
Hidden Bay	1988	B	Flesh	<0.002	—	≤0.0007	—	<0.0001	—	<0.0002	—	<0.004	—
		B	Bone	<0.002	—	<0.0005	—	<0.0009	—	<0.002	—	≤0.070	—
	1986	B	Flesh	≤0.005	—	0.001	—	≤0.0004	—	≤0.0004	—	<0.001	—
		B	Bone	≤0.007	—	0.0009	—	≤0.0004	—	≤0.0004	—	0.007	—
	1984	D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
		C	Flesh	<0.005	—	—	—	<0.005	—	—	—	0.062	—
		C	Bone	0.005	—	—	—	<0.005	—	—	—	<0.01	—
	1982	C	Flesh	<0.002	—	—	—	0.0002	—	—	—	0.008	—
		C	Bone	0.003**	—	—	—	0.0006**	—	—	—	0.07**	—
				0.002	—	—	—	-0.0005	—	—	—	0.002	—
	1981	C	Flesh	<0.004	—	—	—	0.00007**		—	—	0.003**	—
				—	—	—	—	0.0002	—	—	—	0.004	—
		C	Bone	<0.007	—	—	—	0.001**	—	—	—	0.04**	—
				—	—	—	—	0.003	—	—	—	0.5	—

Table 17. (continued)

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
	1980	C	Flesh	0.007	—	—	—	<0.00007	—	—	—	<0.04	—
				0.003*	—	—	—	—	—	—	—	—	—
		C	Bone	0.007	—	—	—	<0.0007**	—	—	—	<0.4	—
				—	—	—	—	0.0001	—	—	—	—	—
		B	Flesh	≤0.001	—	—	—	≤0.0001	—	≤0.0001	—	<0.040	—
		B	Bone	≤0.020	—	—	—	≤0.001	—	≤0.001	—	<0.040	—
	1972	E	Flesh	0.0002	0	0.0001	0	0.0001	0	—	—	0.006	0.002
		E	Bone	0.0036	0	0.0007	0	0.0008	0.0001	—	—	0.04	0.01
Pow Bay	1988	B	Flesh	<0.002	—	0.002	1	<0.0001	—	<0.002	—	≤0.002	—
		B	Bone	<0.002	—	<0.007	—	≤0.002	—	<0.002	—	≤0.020	—
	1984	C	Flesh	<0.005	—	—	—	<0.005	—	—	—	<0.01	—
		C	Bone	<0.005	—	—	—	<0.005	—	—	—	0.04	—
	1982	C	Flesh	<0.002	—	—	—	0.0002	—	—	—	0.02	—
		C	Bone	0.018	—	—	—	0.003	—	—	—	0.04**	—
				0.003**	—	—	—	0.0009**	—	—	—	0.002	—
	1981	C	Flesh	0.004	—	—	—	0.0001	—	—	—	0.004	—
				0.007**	—	—	—	—	—	—	—	—	—
		C	Bone	0.007**	—	—	—	<0.0001	—	—	—	0.04	—
				0.07	—	—	—	—	—	—	—	0.05**	—
	1980	C	Flesh	0.004	—	—	—	<0.00007	—	—	-	<0.04	—
				0.007**	—	—	—	—	—	—	—	—	—
		C	Bone	0.007	—	—	—	<0.0007	—	—	—	<0.4	—
				0.04*	—	—	—	—	—	—	—	—	—
	1980	B	Flesh	≤0.007	—	—	—	≤0.0001	—	≤0.0001	—	<0.040	—
		B	Bone	≤0.040	—	—	—	≤0.0001	—	≤0.001	—	<0.040	—
S. McMahon Lake	1988	F	Flesh	<0.02	—	—	—	0.0001	0	—	—	<0.1	—
		F	Bone	<0.02	—	—	—	0.002	0	—	—	<0.1	—
	1979	G	Flesh	<10	—	—	—	<100 pci/kg		—	—	—	—
Mink Arm	1988	F	Flesh	0.0003	0.00013	—	—	0.00004	0.00003	—	—	<0.1	—
		F	Bone	<0.02	—	—	—	0.0044	0.002	—	—	<0.1	—

Table 17. (continued)

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
N. McMahon Lake	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
		G	Bone	—	—	—	—	<0.004	—	—	—	—	—
Handay Lake	1979	G	Flesh	<0.0004	—	—	—	0.02	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	0.004	—	—	—	—	—
Hatchet Lake Smith Bay	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
		G	Bone	—	—	—	—	0.03	—	—	—	—	—
Waterbury Lake Nicholson Bay	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
		G	Bone	—	—	—	—	<0.004	—	—	—	—	—
Lake W1	1979	G	Flesh	<0.0004	—	—	—	0.01	—	—	—	—	—
Shallow Lake	1979	G	Flesh	<0.0004	—	—	—	0.007	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
		G	Bone	—	—	—	—	0.15	—	—	—	—	—
Lake C1	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
		G	Bone	—	—	—	—	0.01	—	—	—	—	—
McLean Lake	1979	G	Flesh	—	—	—	—	<0.004	—	—	—	—	—
		G	Bone	—	—	—	—	0.01	—	—	—	—	—
		H	Flesh	—	—	—	—	0.0001	0	—	—	0.0005	0

Table 17. (continued)

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
Dawn Lake	1983	N	Flesh	0.0003	0	—	—	0.0001	0	—	—	0.003	0.0004
		N	Bone	0.004	0	—	—	0.0013	0.0005	—	—	0.04	0
	1982	J	Whole (gutted)	0.0009	0	0.0003	0.0001	0.0004	0.0001	—	—	0.001	0.004
	1981	J	Whole (gutted)	0.0009	0	0.0002	0	0.0008	0.0009	—	—	0.02	0.007
Thor Lake	1988	K	Flesh	0.0003	0.0001	—	—	0.00008	0	0.0002	0	0.002	0.0001
		K	Bone	0.002	0.002	—	—	0.0009	0	0.0018	0	0.02	0.0010
Lake Athabasca Langley Bay	1983	O		0.0001	—	—	—	0.001	—	—	—	<0.6	—
				0.006	—	—	—	0.013	—	—	—	<0.1	—

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E = Sawchyn 1973
F = Senes 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984
O = Waite et al. 1988

** Units for data not specified in the source

Table 18. Summary of Fish Metals Data: For Collins Bay and Other N. Saskatchewan Locations: Arctic Grayling 1979.

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
North McMahon	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.2	—
		G	Flesh	—	—	<0.01	—	—	—	—	—	0.6	—

Table 19. Summary of Fish Metals Data: Longnose Sucker 1989.

Wollaston L. Collins Bay	1989	A	Flesh	7.4	5.1	0.30	0.05	11.7	10.7	2.2	1.3	<0.48	0.20
		A	Bone	9.1	1.3	0.07	0.03	3.8	3.6	0.51	0.01	<0.26	0.009

* A = This Study
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D = Sask Environment 1984
E = Sawchyn 1973
F = Serns 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Serns 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

Table 20. Summary of Fish Radionuclide Data: For Collins Bay and Other N. Saskatchewan Locations: Arctic Grayling 1979.

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
North McMahon	1979	G	Flesh	<0.0004	—	—	—	0.007	—	—	—	—	—
		G	Flesh	—	—	—	—	—	—	—	—	—	—

Table 21. Summary of Fish Radionuclide Data: Longnose Sucker 1989.

Wollaston Lake Collins Bay	1989	A	Flesh	0.0001	0.0004	0.002	0.002	<0.00007	0.00001	<0.0001	0.00006	0.01	0.02
		A	Bone	0.012	0.02	0.002	0.002	<0.002	0.003	<0.0017	0.0002	0.20	0.37

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F = Senes 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

Table 22. Summary of Fish Metals Data: For Collins Bay and Other N. Saskatchewan Locations: White Sucker 1979 to 1988.

Location		Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g	
					X	SD	X	SD	X	SD	X	SD	X	SD
South McMahon Lake		1988	F	Flesh	—	—	0.0003	0.00004	0.12	0.02	0.29	0.03	0.05	0.018
			F	Bone	—	—	0.004	0.0002	1.78	0.0	1.03	0.20	0.20	0.13
Mink Arm		1988	F	Flesh	—	—	0.0004	0.0002	0.06	0.004	0.21	0.008	0.03	0.008
			F	Bone	—	—	0.006	0.002	1.71	0	0.93	0.09	0.56	0.09
McLean Lake		1979	H	Flesh	—	—	—	—	—	—	—	—	—	—
Dawn Lake		1982	J	Whole (gutted)	—	—	—	—	—	—	—	—	—	—
Beaverlodge	**	1983	L	Whole	0.01	0.23	—	—	0.01	0.008	0.04	0.02	—	—
	***	1982	M	Skin	—	—	—	—	—	—	—	—	—	—
				Flesh	—	—	—	—	—	—	—	—	—	—
				Bone	—	—	—	—	—	—	—	—	—	—
Milliken Lake	**	1983	L	Whole	0.05	0.04	—	—	0.01	0.005	0.03	0.009	—	—
	***	1982	M	Skin	—	—	—	—	—	—	—	—	—	—
			M	Flesh	—	—	—	—	—	—	—	—	—	—
			M	Bone	—	—	—	—	—	—	—	—	—	—

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D = Sask Environment 1984
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G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

** Average of 60% used to convert metals data from dry weight to wet weight.
*** Standard error recorded in place of standard deviation.

Table 23. Summary of Fish Radionuclide Data: For Collins Bay and Other N. Saskatchewan Locations: White Sucker 1979 to 1988.

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
South McMahon Lake	1988	F	Flesh	<0.02	—	—	—	0.00006	0	—	—	0.001	0
		F	Bone	0.004	0.002	—	—	0.0018	0.0009	—	—	0.004	0.02
Mink Arm	1988	F	Flesh	<0.02	—	—	—	0.000	0	00	00	0.002	0.001
		F	Bone	0.004	0.002	—	—	0.004	0.002	—	—	0.09	0
McLaen Lake	1979	H	Flesh	—	—	—	—	0.0002	0.00007	—	—	0.0006	0
Dawn Lake	1982	J	Whole (gutted)	0.0010	0	0.0002	0	0.0002	0	—	—	0.002	0.01
Beaverlodge	** 1983	L	Whole	—	—	—	—	—	—	—	—	—	—
	*** 1982	M	Skin	0.01	0.002	—	—	0.02	0.002	—	—	3.02	0.17
			Flesh	0.001	0.0002	—	—	0.001	0.0002	—	—	0.06	0.01
			Bone	0.03	0.01	—	—	0.08	0.01	—	—	13.67	0.96
Milliken Lake	** 1983	L	Whole	—	—	—	—	—	—	—	—	—	—
	*** 1982	M	Skin	0.002	0.001	—	—	0.0007	0.0001	—	—	0.04	0.01
		M	Flesh	0.0003	0.00004	—	—	0.0001	0.00002	—	—	0.01	0.01
		M	Bone	0.008	0.001	—	—	0.002	0.0003	—	—	0.14	0.02

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G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

** Average of 60% used to convert metals data from dry weight to wet weight.
*** Standard error recorded in place of standard deviation.

Table 24. Summary of Fish Metals Data: For Collins Bay and Other N. Saskatchewan Locations: Walleye 1979 to 1984.

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake															
Collins Bay	1984	D	Flesh	—	—	—	—	0.24	0.18	0.21	0.04	0.10	0.01	0.04	0
		D	Bone	—	—	—	—	0.76	0.23	1.1	0	1.29	1.71	0.74	0.03
Hidden Bay	1984	D	Flesh	—	—	—	—	0.34	0.24	0.42	0.24	0.20	0.15	0.13	0.12
		D	Bone	—	—	—	—	0.70	0.29	0.62	0.06	1.74	2.21	0.67	0.03
McLean Lake	1980	I	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		I	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1979	H	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	0.2	—	—	—

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D = Sask Environment 1984
E = Sawchyn 1973
F = Senes 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

Table 25. Summary of Fish Radionuclide Data: For Collins Bay and Other N. Saskatchewan Locations: Walleye 1979 to 1984.

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake													
Collins Bay	1984	D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
Hidden Bay	1984	D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
McLean Lake	1980	I	Flesh	—	—	—	—	0.0003	0.0003	—	—	0.005	0.002
		I	Bone	0.004	0.002	—	—	0.001	0.008	—	—	0.03	0
	1979	H	Flesh	—	—	—	—	0.0001	0	—	—	0.0006	0
	1979	G	Flesh	<0.0004	—	—	—	<0.0004	—	—	—	—	—

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F = Sanes 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Sanes 1981
J = MacLaren 1982
K = Melville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

Table 26. Summary of Fish Metals Data: For Collins Bay and Other N. Saskatchewan Locations: Lake Trout 1978 to 1984.

Location	Date	Source * Type	Sample	Al ug/g		As ug/g		Cr ug/g		Cu ug/g		Ni ug/g		Mo ug/g	
				X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake															
Hidden Bay	1984	D	Flesh	—	—	—	—	0.26	0	0.34	0	0.14	0	0.05	0
		D	Bone	—	—	—	—	0.72	0	0.58	0	0.09	0	0.50	0
	1980	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Pow Bay	1984	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1982	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1981	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
	1980	C	Flesh	—	—	—	—	—	—	—	—	—	—	—	—
		C	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Henday Lake	1978	G	Flesh	—	—	—	—	—	—	0.38	0.02	0.02	0.14	—	—
Hatchet Lake															
Smith Bay	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	0.60	—	—	—	—	—
		G	Bone	—	—	—	—	—	—	—	—	—	—	—	—
Waterbury Lake															
Nicholson Bay	1979	G	Flesh	—	—	<0.01	—	—	—	—	—	4.3	—	—	—

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H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Malville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

Table 27. Summary of Fish Radionuclide Data: For Collins Bay and Other N. Saskatchewan Locations: Lake Trout 1978 to 1984.

Location	Date	Source *	Sample Type	Pb-210 Bq/g		Po-210 Bq/g		Ra-226 Bq/g		Th-230 Bq/g		U uq/g	
				X	SD	X	SD	X	SD	X	SD	X	SD
Wollaston Lake													
Hidden Bay	1984	D	Flesh	—	—	—	—	—	—	—	—	—	—
		D	Bone	—	—	—	—	—	—	—	—	—	—
	1980	C	Flesh	<0.0007	—	—	—	0.00007	—	—	—	<0.04	—
		C	Bone	0.01	—	—	—	<0.0007	—	—	—	<0.4	—
Pow Bay	1984	C	Flesh	<0.005	—	—	—	<0.005	—	—	—	<0.01	—
		C	Bone	<0.008	—	—	—	<0.005	—	—	—	<0.01	—
	1982	C	Flesh	0.002	—	—	—	0.0003	—	—	—	0.04	—
		C	Bone	0.004	—	—	—	0.0006	—	—	—	0.01	—
	1981	C	Flesh	0.004	—	—	—	0.00004	—	—	—	0.002	—
				0.007**	—	—	—	0.0002**	—	—	—	0.005**	—
		C	Bone	0.0007	—	—	—	<0.0006	—	—	—	0.01	—
	1980	C	Flesh	<0.0007	—	—	—	0.00007	—	—	—	<0.04	—
		C	Bone	0.03	—	—	—	<0.0007	—	—	—	<0.4	—
Henday Lake	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
Hatchet Lake													
Smith Bay	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—
	1978	G	Flesh	—	—	—	—	—	—	—	—	—	—
		G	Bone	—	—	—	—	<0.004	—	—	—	—	—
Waterbury Lake													
Nicholson Bay	1979	G	Flesh	<0.0004	—	—	—	<0.004	—	—	—	—	—

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D = Sask Environment 1984
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F = Senes 1988
G = Beak 1980
H = MacLaren and SRC 1979
I = MacLaren and Senes 1981
J = MacLaren 1982
K = Malville et al. 1989
L = SRC unpublished
M = Swanson 1985
N = MacLaren 1984

** units for data not specified in the source.

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APPENDIX

OXYGEN/TEMPERATURE/CONDUCTIVITY PROFILES

Collins Bay Site #3

Depth (m)	Temperature (^{o}C)	Oxygen (ppm)	Conductivity (umhos)
0.5	0.2	13.2	10
1.0	0.2	13.2	10
2.0	0.2	13.2	10
2.5	0.2	13.2	10

pH 6.9 at 1 m
6.8 at 2 m

alkalinity 4.5 ppm at 1 m
4.0 ppm at 2 m

Collins Bay Site #4

Depth (m)	Temperature (^{o}C)	Oxygen (ppm)	Conductivity (umhos)
1	0.5	12.9	12
2	0.6	12.2	12
3	0.8	12.0	14
4	1.0	11.8	18
5	1.2	11.4	18
6	1.2	11.4	18
7	1.4	11.2	18
8	1.6	11.1	18
9	1.8	11.0	18

pH 7.2 at 1 m
7.0 at 5 and 9 m

alkalinity 5.5 ppm at 1 m
6.5 ppm at 5 m
7.0 ppm at 9 m

FISH AGE DATA FOR FISH ANALYSED FOR RADIONUCLIDES AND METALS

Longnose suckers:

Sample	Sex	Age
1	M	unreadable
2	M	16+
3	F	18+
4	F	14+
5	F	19+

Lake Whitefish:

Fish	Sample	Sex	Age
1	1	M	15+
2	1	F	11+
3	2	M	12+
4	2	M	13+
5	3	M	18+
6	3	M	16+
7	3	M	11+
8	4	F	16+
9	4	F	13+
10	5	M	12+
11	5	F	12+